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VALVE OPENING-TIME REQUIREMENTS FOR LB/TS

R. A. BERRY
G. D. LASSAHN
EG&G IDAHO, INC. (INEL)

NOVEMBER 1988

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U.S. ARMY LABORATORY COMMAND

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Computer calculations were performed to determine the maximum allowable valve opening times for producing sharply defined shocks of certain specifications ranging from 13.8 kPa to 241 kPa in the proposed Large Blast/Thermal Simulator for the U.S. Army Ballistic Research Laboratory. The maximum allowable valve opening times range from 63 milliseconds for the highest shock overpressure to 21 milliseconds for the lowest shock overpressure in the specified overpressure range.

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VALVE OPENING TIME REQUIREMENTS FOR LB/TS

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1. INTRODUCTION

The Ballistic Research Laboratory (BRL) of the U.S. Army is designing a Large Blast/Thermal Simulator (LB/TS), which is a proposed facility for creating pressure and thermal transients like those that occur near nuclear explosions.[1] The LB/TS is basically a large shock tube with area changes along its length. Unlike a conventional shock tube, which uses rupture diaphragms to separate the high pressure driver region from the low pressure driven region, it is desirable to utilize fast-opening valves in the LB/TS for wave shaping purposes as well as operational efficiency. However, with real valves, a finite opening time results in a compression wave with a finite rise time. The question then arises as to whether the compression wave will steepen to an adequate shock profile within the specified wave propagation distance, to simulate the desired blast wave. In support of this design effort, the Mathematical Analysis Unit at the Idaho National Engineering Laboratory (INEL) has done calculations to determine the maximum throat valve opening times allowable for the creation of certain shock waves in the LB/TS test section. Calculations were done for 9 specific cases specified by the BRL, representing 9 different initial conditions in the shock tube driver. All the calculations were done with the BRL-Q1D computer code[2]. This report summarizes the results of the valve opening calculations.

2. CALCULATIONS

For the present studies, the LB/TS was represented as shown in Figure 1 and described in Table 1. We are interested in the initial magnitude and rise time (not the later decay) of the shock at the test section 103.5 meters from the valve. The objective of the present study is to determine how fast the valve must open to allow the overpressure to rise from 5% to 95% of the plateau value in 0.5 milliseconds or less. We are not concerned with reflections from the end of the shock tube, which arrive too late to affect the shock front of interest. This allows us to model a shock tube substantially shorter than the real LB/TS, thereby saving some computer costs.

Calculations were done for the 9 cases listed in Table 2, representing different initial temperature and pressure conditions in the driver. Case 9 was different from the other 8 in that the shock tube geometry was a little different (see Table 1) and the valve was opened to a maximum of 43.75% instead of 100%.

The valve was represented as a parabolic constriction with a total length of 2 meters, located in the middle of the throat. The valve opening was represented as a linear function of time, from 0.1% open at time zero to 100% open (43.75% open for case 9) at the specified valve opening time. In addition to these calculations with the valve opening gradually, a reference calculation was done with the valve opened instantaneously for each case, to insure adequate resolution of the shock wave structure with the mesh used and, in some instances, to compare certain features of the wave structures.

Table 1: Shock Tube Geometry

	cases 1-6	cases 7-8	case 9
driver length	80.	20.	20.
driver diameter	5.490	5.490	5.440
converging nozzle length	2.	2.	2.
throat length	4.	4.	4.
throat diameter	2.743	2.743	1.8[illegible]
diverging nozzle length	4.	4.	4.
expansion tube length	110.	110.	110.
expansion tube diameter	14.494	14.494	14.494

(all dimensions are in meters)

TABLE 2: Calculation Results

case	pressure ratio	temperature ratio	nominal over-pressure [kPa]	reference over-pressure [kPa]	maximum valve opening time [second]
1	118.0	2.235	241.3	247.0	0.063
2	102.5	2.009	206.8	213.6	0.062
3	83.5	1.825	172.4	174.5	0.061
4	69.2	1.652	137.9	142.7	0.055
5	54.0	1.471	103.4	107.2	0.044
6	39.5	1.228	68.9	74.0	0.050
7	19.5	1.094	34.5	39.6	0.035
8	7.0	1.040	13.8	15.57	0.021
9	8.9	1.040	13.8	4.634	0.026

The calculations were done on INEL's CRAY X/MP-24 computer. Two minor modifications were made to the BRL-Q1D code: the sizes of the grid-dependent arrays were increased, and the plot and print output of time-dependent arrays was not started until the shock reached the first measurement station. For cases 8 and 9, the code was further modified by overlaying some large arrays, to decrease computer memory requirements and thereby improve computer access and turn-around time.

The BRL-Q1D code includes two options for the numerical method: the Beam-Warming and the MacCormack methods. For these calculations, the Beam-Warming method was used, with the BRL-recommended values of 1.0 for the Courant number and 0.04 for the smoothing coefficient. Preliminary estimates suggested that 10000 grid points would be adequate for these calculations, and this number was used successfully for cases 1-6. More grid points were required for cases 7-9.

3. RESULTS

The results for case 1 are given here in some detail; results for the other cases are given in much less detail, only as is necessary to describe significant differences from the results for case 1.

Figures 2-15 indicate the temporal and spatial dependence of some important variables calculated by the BRL-Q1D code for case 1 with the valve instantaneously opened 100%. In Figures 2-13, the horizontal axis is the normalized distance along the length of the shock tube. The actual total length corresponding to the normalized length of 1 is indicated by the value of L_{ref} (200 meters for case 1) printed at the top left corner of the page. The profile of the shock tube is indicated above the data plot, on the same horizontal scale as the data plot. The dependent variables plotted on the vertical scale in Figures 2-13 are also normalized to reference values as described in the BRL-Q1D code documentation.[2] The number printed just above the right end of each curve in Figures 2-13 is the time corresponding to that curve, in seconds. In Figures 10-13, the horizontal scale is expanded enough so that the individual points of the spatial grid are discernible, indicated by the vertical lines in the shock tube profile drawn above the graph proper. These graphs with high spatial resolution clearly indicate the spatial spread of the computed shock front, which is useful in evaluating the adequacy of the numerical method.

Figures 14 and 15 are graphs of overpressure (solid line) and dynamic pressure (dashed line) versus time, at the test location specified by the value listed for X-sta at the top of the page. The indicated distance of 97.5 meters from the beginning of the expansion tube corresponds to the required 103.5 meters from the center of the valve.

The data of most immediate interest is the overpressure versus time data indicated by the solid curves in Figures 14 and 15. This overpressure rises abruptly -- in a fraction of a millisecond -- when the shock arrives at the test location. At the top of this step is a small overshoot that is an artifact of the numerical procedures and is not indicative of a real phenomenon; the actual overpressure step is better indicated by extrapolating the almost-horizontal curve from the right of the step into the region of the step itself. This extrapolation procedure was used to estimate the overpressure step in all the studies reported here.

After the initial shock transient, the overpressure approaches a constant value, a plateau value, which is different for each of the 9 cases. This plateau value is used as the reference overpressure for each case.

Figures 16-29 illustrate the effect of the valve opening gradually instead of instantaneously. These figures represent a valve opening time of 65 milliseconds, which is close to the maximum allowable valve opening time for case 1. The major effect is to decrease the magnitude of the overpressure step and to increase the slope of the overpressure versus time curve after the initial shock. The rise time for the initial step is not noticeably changed by the gradual opening of the valve. Since the slope of the overpressure versus time curve after the initial shock is practically zero on a millisecond time scale, the acceptance criterion is essentially equivalent to the requirement that the magnitude of the overpressure step with the valve opened gradually be at least 95% of the reference overpressure. Thus, the procedure for estimating the maximum allowable valve opening time was to try different opening times and check whether the shock overpressure step was at least 95% of the reference value. (Of course the shock rise time was also checked for each run, to be sure that it was less than 0.5 ms.)

This case 1 description is representative of the results for cases 1-5. Case 6 and 7 gave results similar to those described for case 1, except that the overpressure decreased slightly instead of increasing after the initial shock for the calculations in which the valve was opened instantaneously. This difference was not important in estimating the maximum acceptable valve opening time.

Cases 8 and 9 gave qualitatively different results, as indicated in Figures 30-39 for case 8 with the valve instantaneously opened. In these cases, the initial shock was followed after a few milliseconds by a second shock that raised the overpressure to a value substantially higher than that of the first shock. The timing and magnitude of the second shock depend on the details of the geometry in the throat region of the shock tube. Figures 40-93 show some detailed plots for case 8 with the valve instantaneously opened, and Figure 94 shows an x-t plot for this case. The second shock moves a little faster that the first shock, but does not quite overtake the first shock in the 103.5 meter travel distance to the test station. It appeared that moving the valve closer to the end of the throat would decrease the initial delay between the first and second shocks and perhaps allow the second shock to overtake and merge with the first shock before they reached the test location. This change in the valve location was tried and found effective for this particular problem; unfortunately, this created another shock even later, so that the overall effect was not significantly changed.

The general conclusion drawn from this examination of case 8 is that the details of the shock tube geometry near the valve can cause irregular behavior of the overpressure versus time plot for the shock front, more complicated than the simple step followed by an almost flat region. In fact, this same irregular behavior occurs in all cases (note Figure 3), but in the higher pressure cases the irregular structure is merged into one simple shock before the shock reaches the measurement station.

Of course the simple shock tube geometry assumed here and the one-dimensional fluid flow calculation used here may not accurately represent the actual shock tube valve, throat, and nozzle behavior; nevertheless, it would not be surprising if phenomena qualitatively similar to the double shock behavior calculated for case 8 actually occurred in the real LB/TS. The question of immediate importance here is whether the model is realistic or informative enough to be useful, and whether (and how) to proceed with the studies of acceptable valve opening times for cases 8 and 9. The BRL personnel consulted[3] on this matter suggested prodeeding with the calculations, with the understanding that the results might not be taken at face value. Thus, the results presented here for cases 8 and 9 should be regarded as plausible but perhaps not very accurate estimates of the actual shock tube behavior. These results are a little sketchy, but more detailed studies did not seem warranted in view of the high cost and limited validity of computer calculations for the low-pressure cases like cases 8 and 9.

Overpressure versus time plots for cases 8 and 9 are shown in Figure 38 and Figures 95-100. The overpressure step associated with the first shock front appears to vary in a consistent manner with valve opening time, if the valve is opened gradually instead of instantaneously, and the results obtained from considering only this first shock front fit reasonably well with the results from cases 1-7. Therefore, despite the irregular nature of the overpressure versus time curve near the shock front, cases 8 and 9 were finally treated in the same manner as the other cases, with the overpressure step at the first shock front being considered the critical factor.

For the case 9 calculations with valve opening times of 20 and 30 milliseconds, the shock front rise time was a little greater than the required 0.5 milliseconds. However, previous experience indicates that the parameters of interest are not very sensitive to this factor, and the high calculation cost prohibited repeating these calculations with smaller step sizes to obtain the required rise time.

The results of these valve opening time studies are summarized in Figures 101-103, which indicate the magnitude of the shock overpressure step versus valve opening time for each of the 9 cases studied. Interpolation of these curves gives the maximum allowable valve opening time for each case, listed in Table 2 and graphed versus driver pressure to ambient pressure ratio in Figure 104. This curve does show a general trend, but it is not smooth. This lack of smoothness is at least partly attributed to the fact that the maximum allowable valve opening time is not a function of pressure ratio alone; it also depends on the temperature ratio, which is not a perfectly smooth function of the pressure ratio (see Figure 105) for the cases considered here.

4. CONCLUSIONS

The calculations done here indicate that the maximum allowable valve opening time is about 63 milliseconds for case 1, and somewhat less for the other, lower-pressure cases, as indicated in Table 2. The results for cases 1-7 are believed to be realistic; the results for cases 8 and 9 must be regarded with some skepticism. More reliable results would require a multidimensional computer model that is somewhat more complicated and substantially more expensive to run than the model used in this work.

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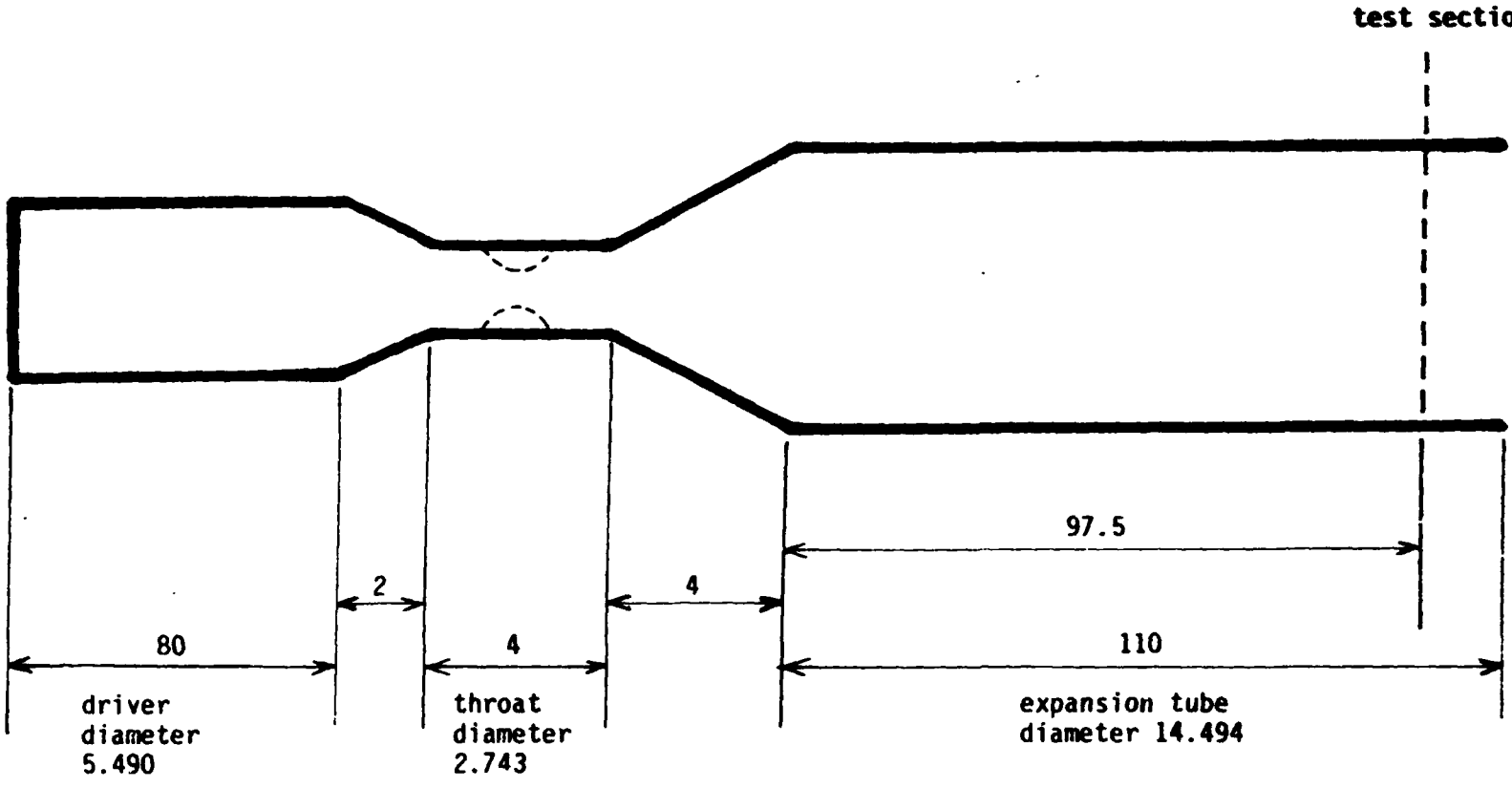


Figure 1. Diagram (not to scale) of shock tube for Case 1.

pressure

CASE~ 1n: BRL1 - PLOT 1
Offset, Δy = 1.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940

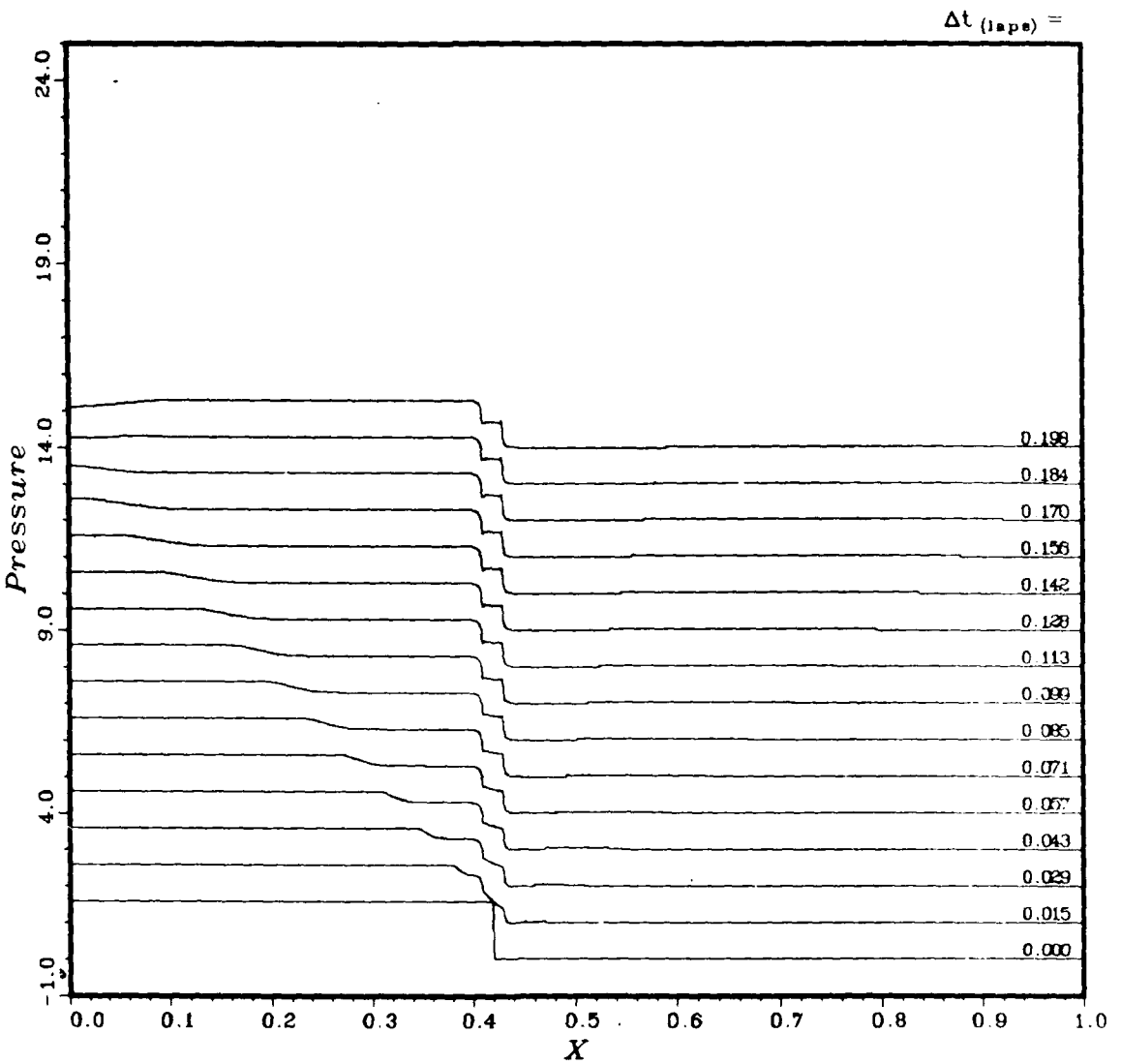


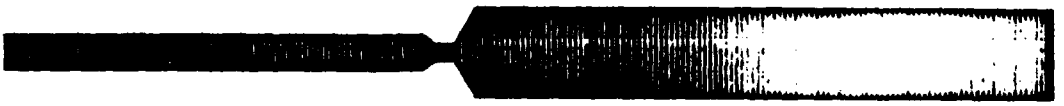
Figure 2. Pressure versus distance, case 1, zero opening time

PLOT 2 19.09.16 WED 9 DEC, 1987 JOB=P1020846, ISSCO DISSPLA 10.0

pressure

CASE~ 1n: BRL1 – PLOT 1
Offset, Δy = 0.020

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940



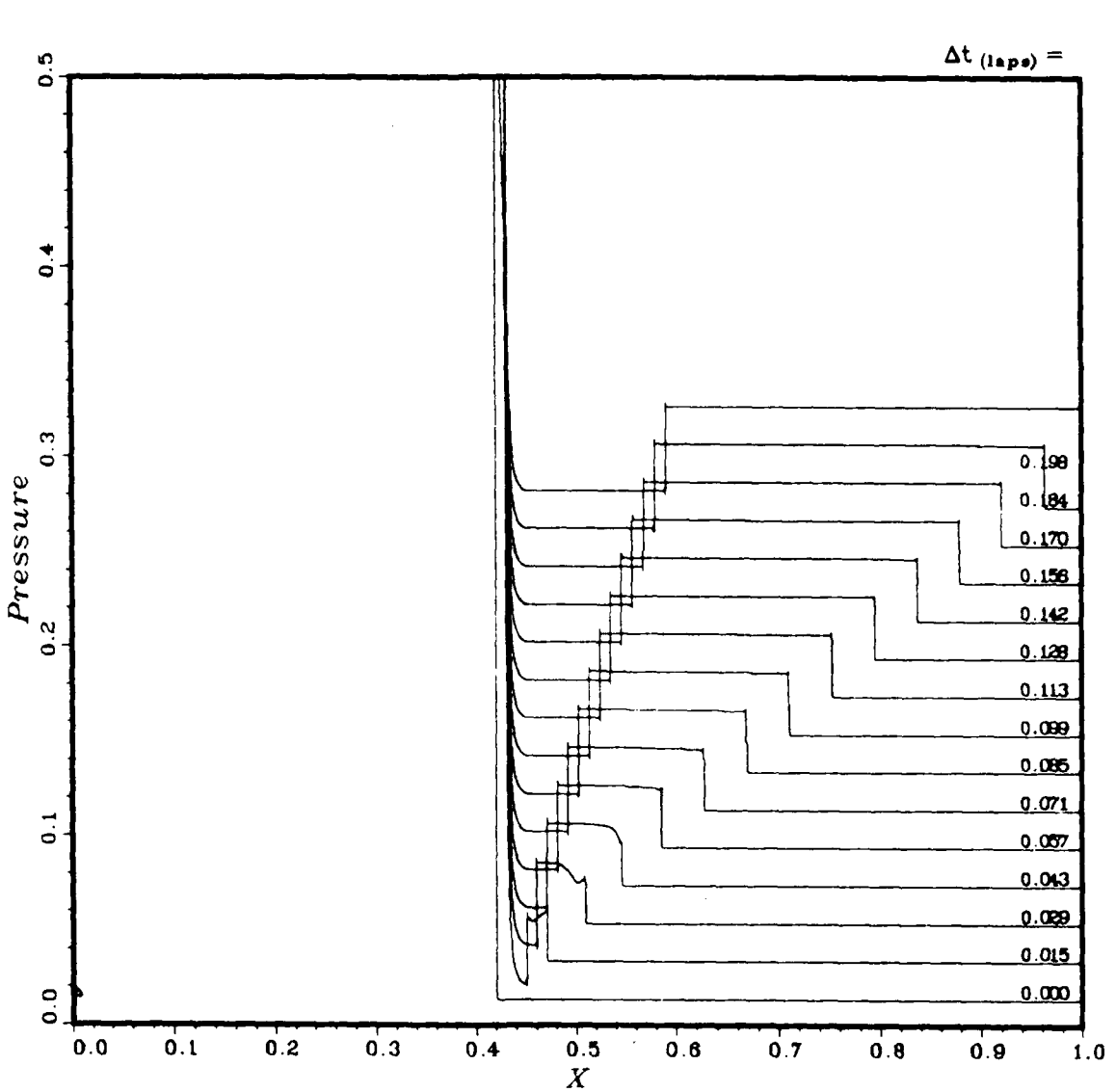


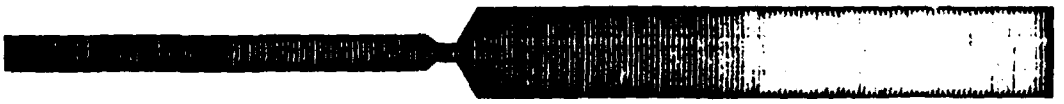
Figure 3. Magnified pressure versus distance, case 1, zero opening time

PLOT 1 19.08.58 WED 9 DEC, 1987 JOB=P1020846, ISSCO DISSPLA 10.0

density

CASE~ 1n: 3PL1 PLOT 1
Offset, Δy = 0.100

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940



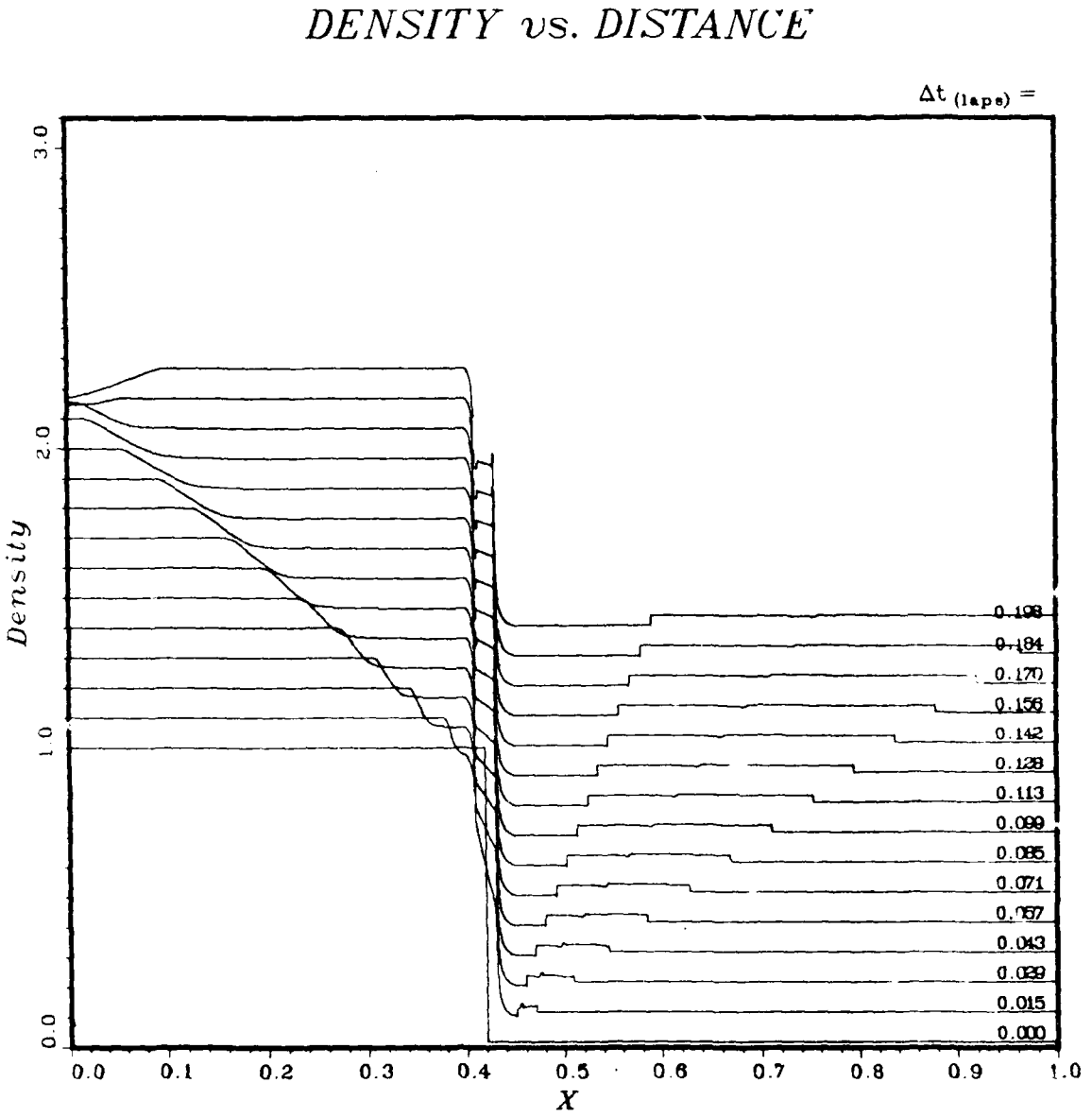


Figure 4. Density versus distance, case 1, zero opening time

density

CASE~ 1n: BRL1 – PLOT
Offset, Δy = 0.010

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.935, 0.938, 0.940

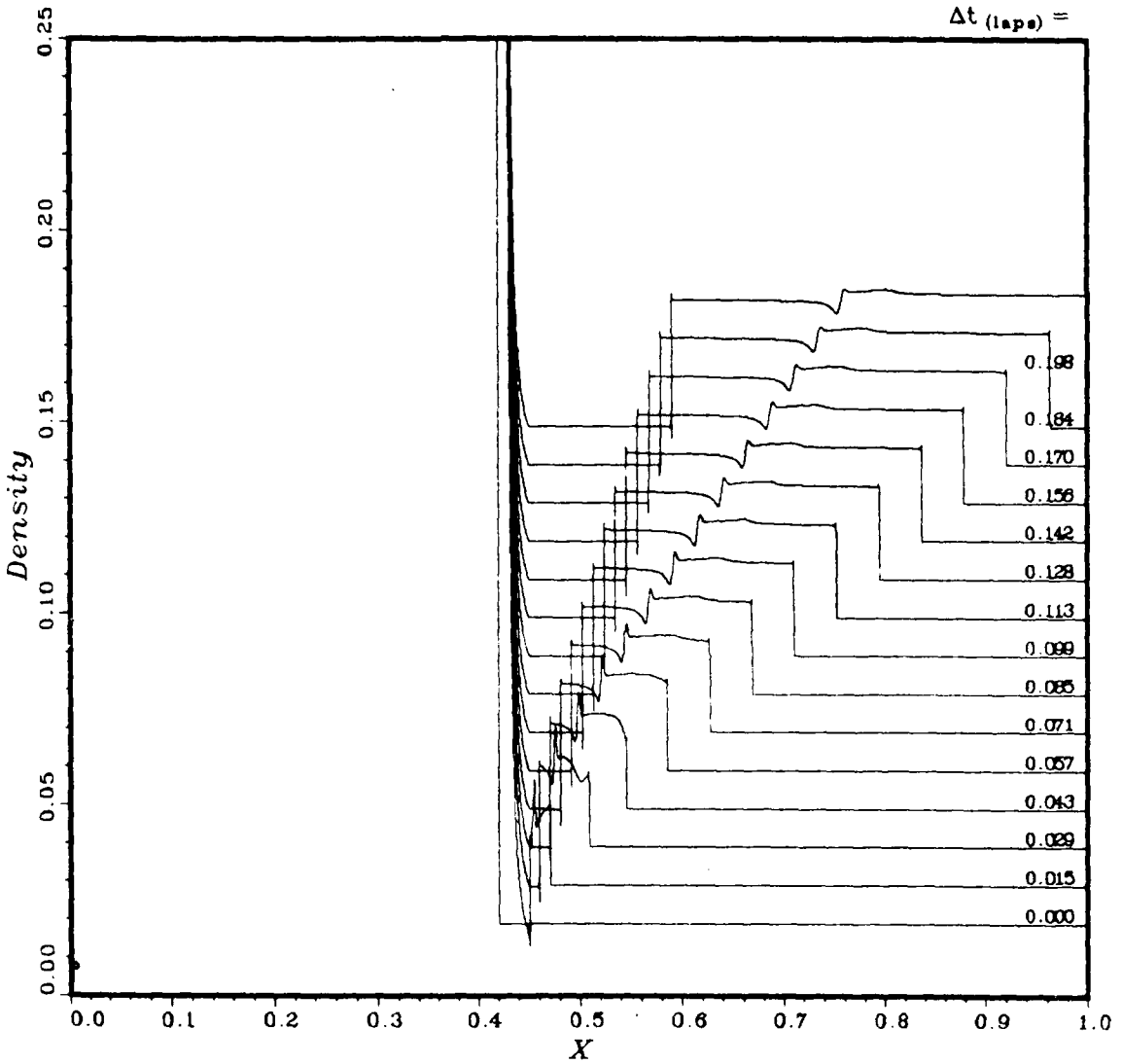


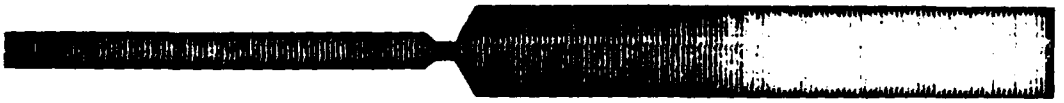
Figure 5. Magnified density versus distance, case 1, zero opening time

PLOT 3 19.09.30 WED 9 DEC, 1987 JOB=P1020846, ISSCO DISSPLA 10.0

velocity

CASE~ 1n: BRL1 – PLOT 1
Offset, Δy = 3.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940



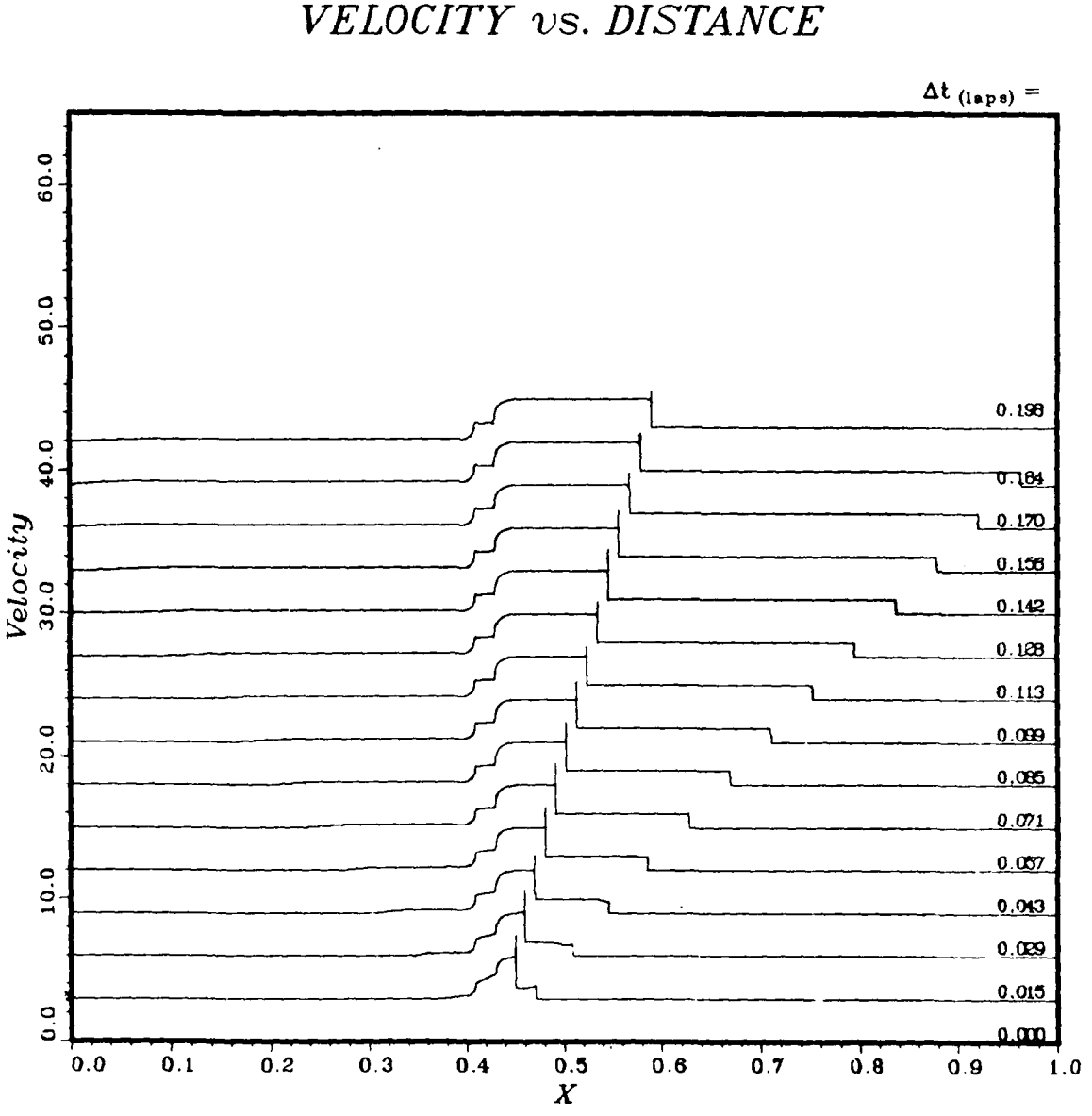


Figure 6. Velocity versus distance, case 1, zero opening time

PLOT 4 19.10.05 WED 5 DEC, 1987 JOB#:ID20846, ISSCO DISSPLA 10.0

velocity

CASE~ 1r: redo 1n, check q01 – PLOT 1
Offset, Δy = 0.200

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940

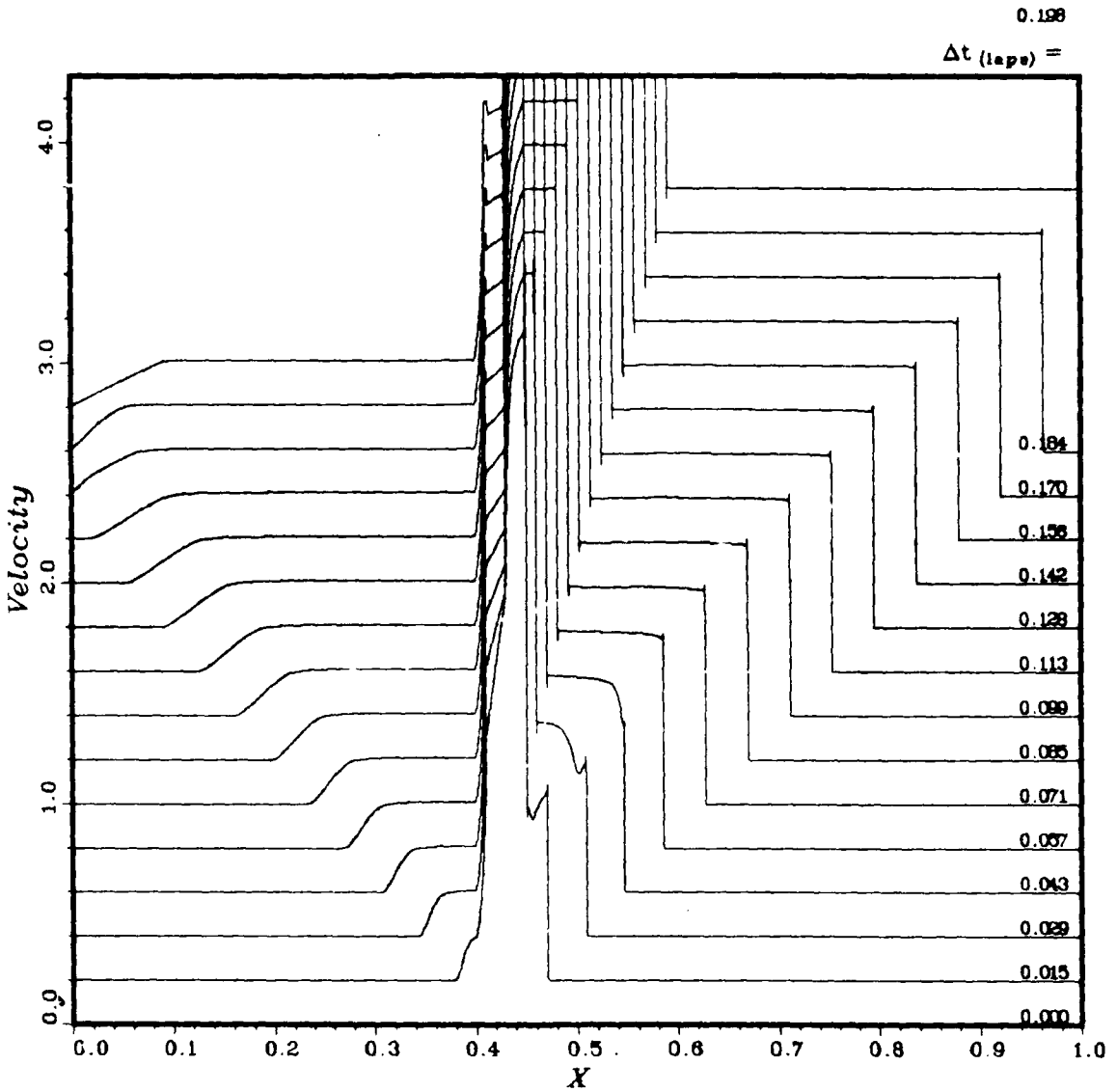


Figure 7. Magnified velocity versus distance, case 1, zero opening time

PLOT 4 10.14.15 MON 11 JAN, 1988 JOB-P1050B9 , ISSCO DISSPLA 10.0

sound speed

CASE~ 1n: BRL1 – PLOT 1
Offset, Δy = 1.500

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940

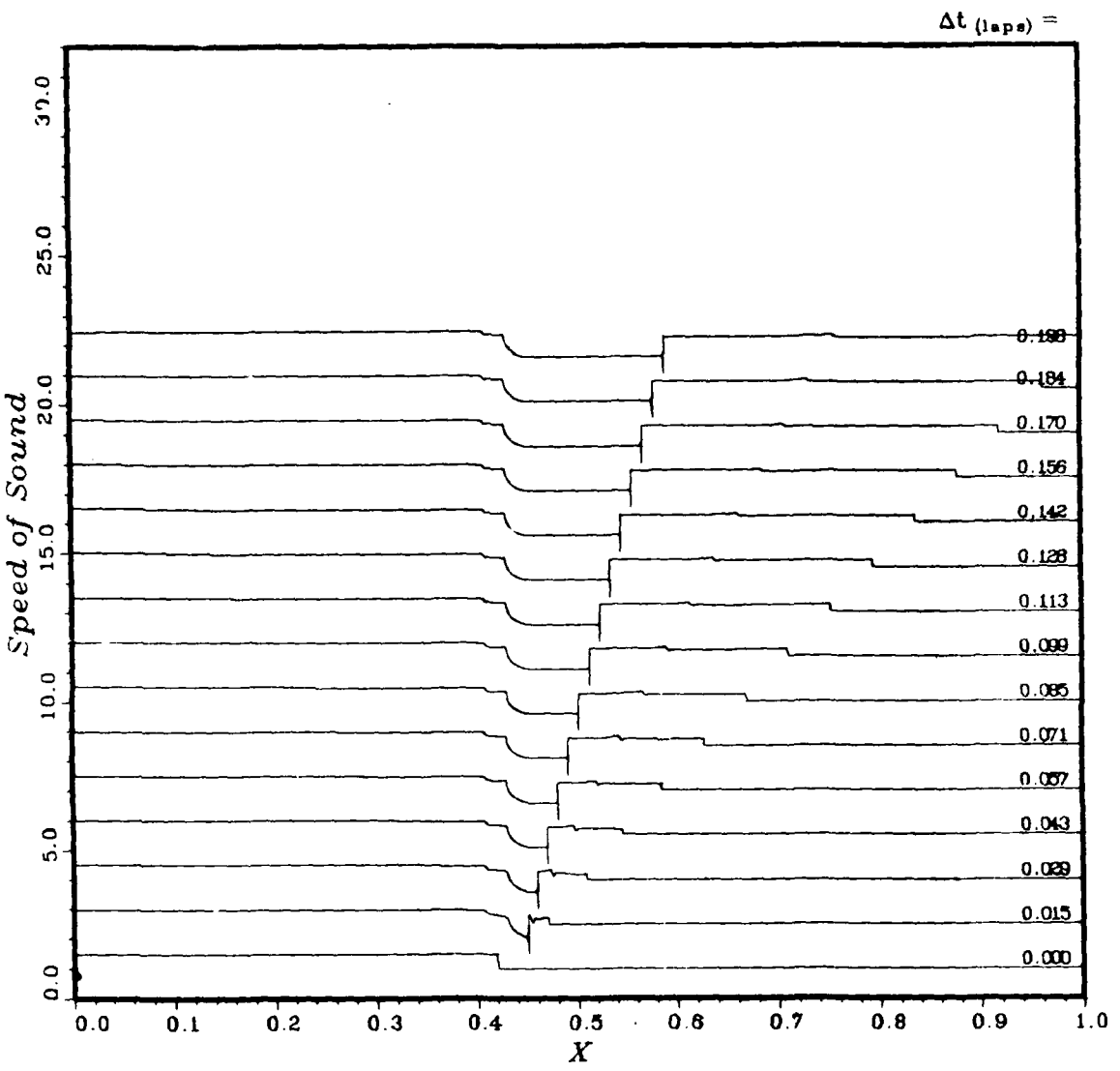


Figure 8. Sound speed versus distance, case 1, zero opening time

sound speed

CASE~ 1r: redo 1n, check q01 – PLOT 1
Offset, Δy = 0.030

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.935, 0.939, 0.940

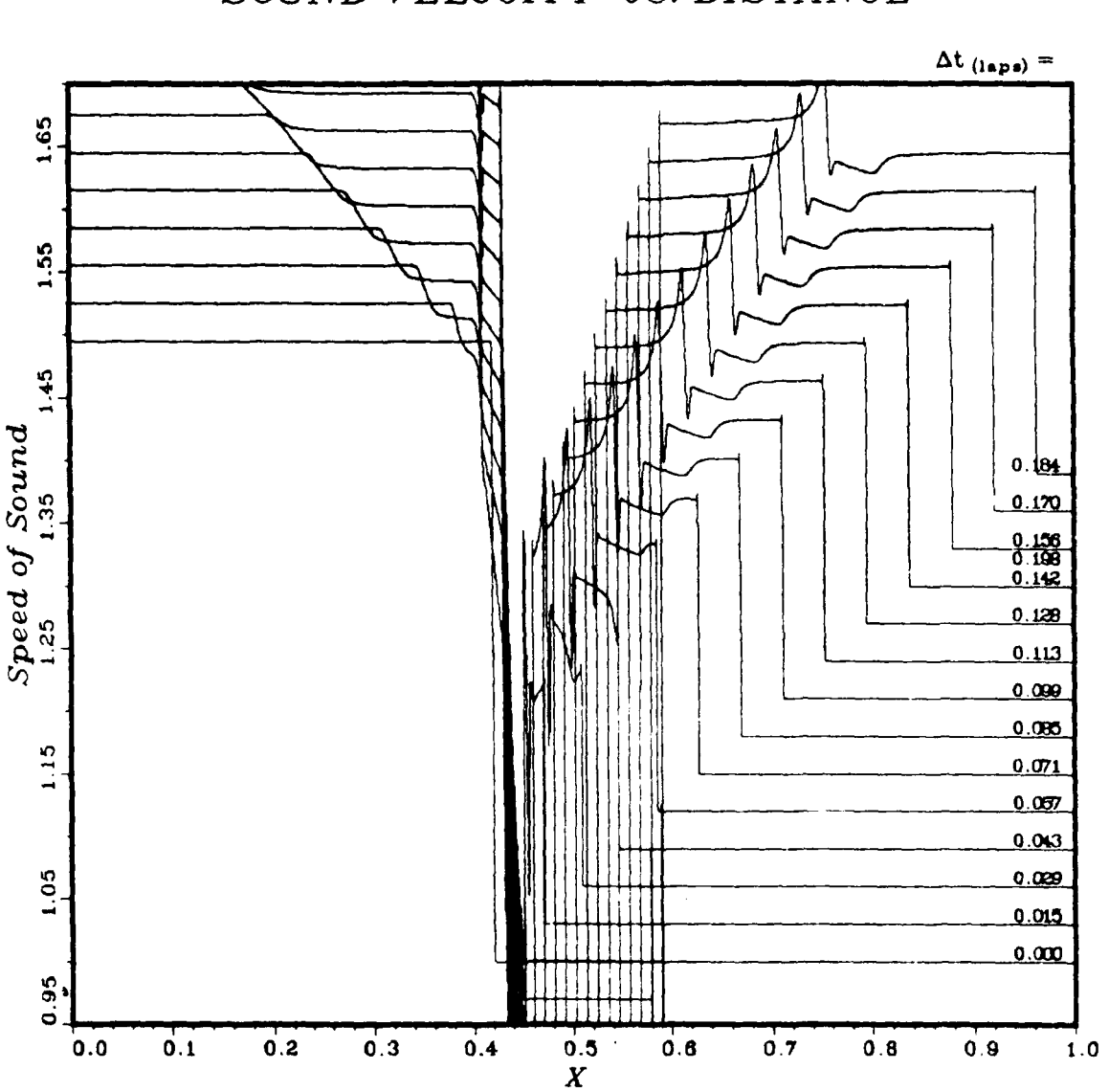


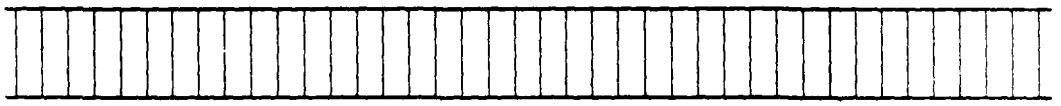
Figure 9. Magnified sound speed versus distance, case 1, zero opening time

PLOT 6 10.04.47 MON 11 JAN, 1988 JOB-PID5089 , ISSCO DISSPLA 10.0

pressure

CASE~ 1n: BRL1 – PLOT 3
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940



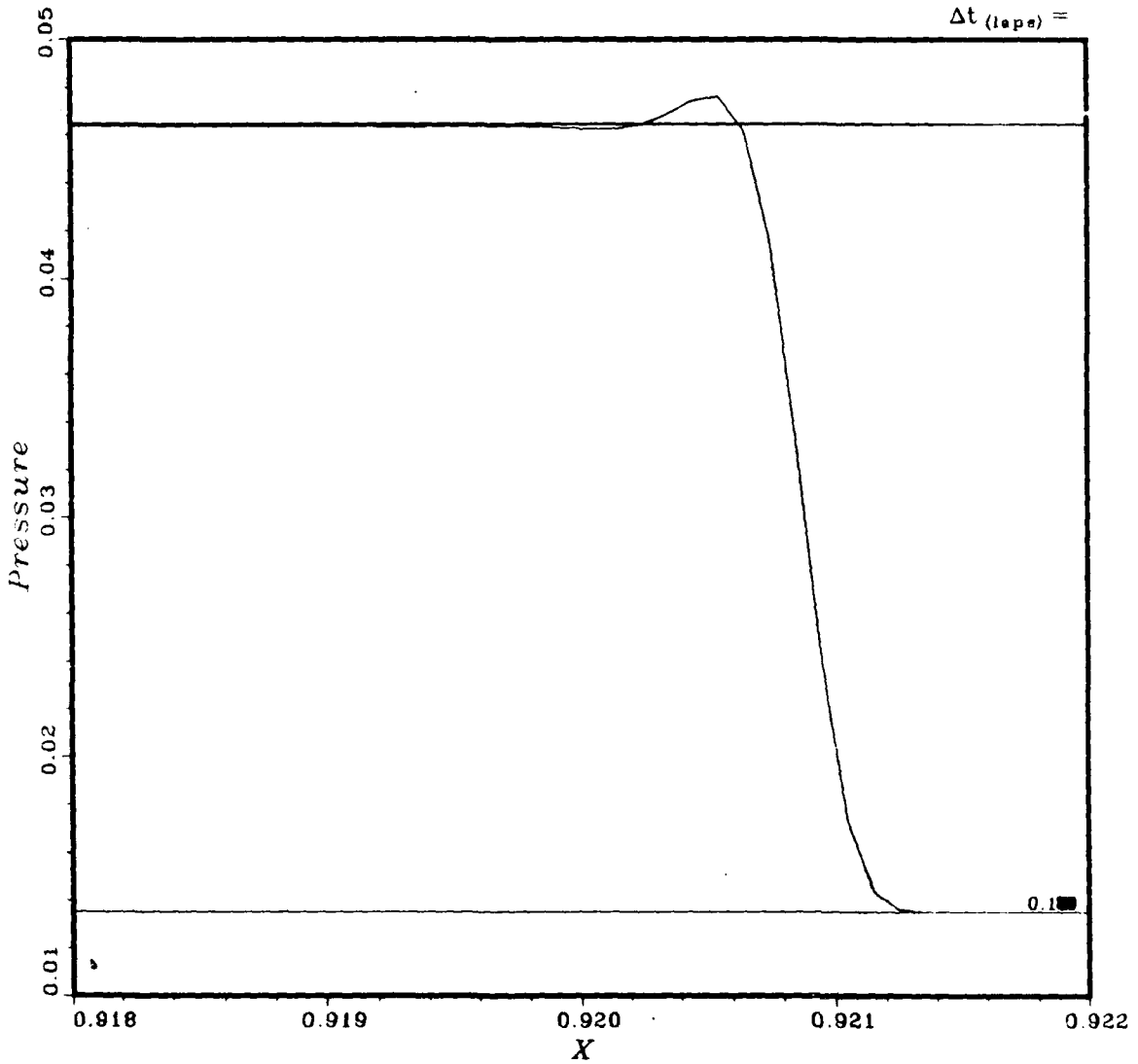


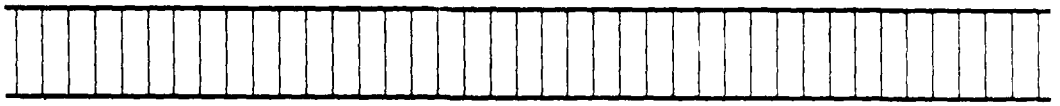
Figure 10. Shock front detail, pressure versus distance, case 1, zero opening time

PLOT 3 08.19.09 THUR 10 DEC, 1987 JOB=P1D30086, ISSCO DISSPLA 10.0

density

CASE~ 1n: BRL1 – PLOT 3
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.935, 0.938, 0.940



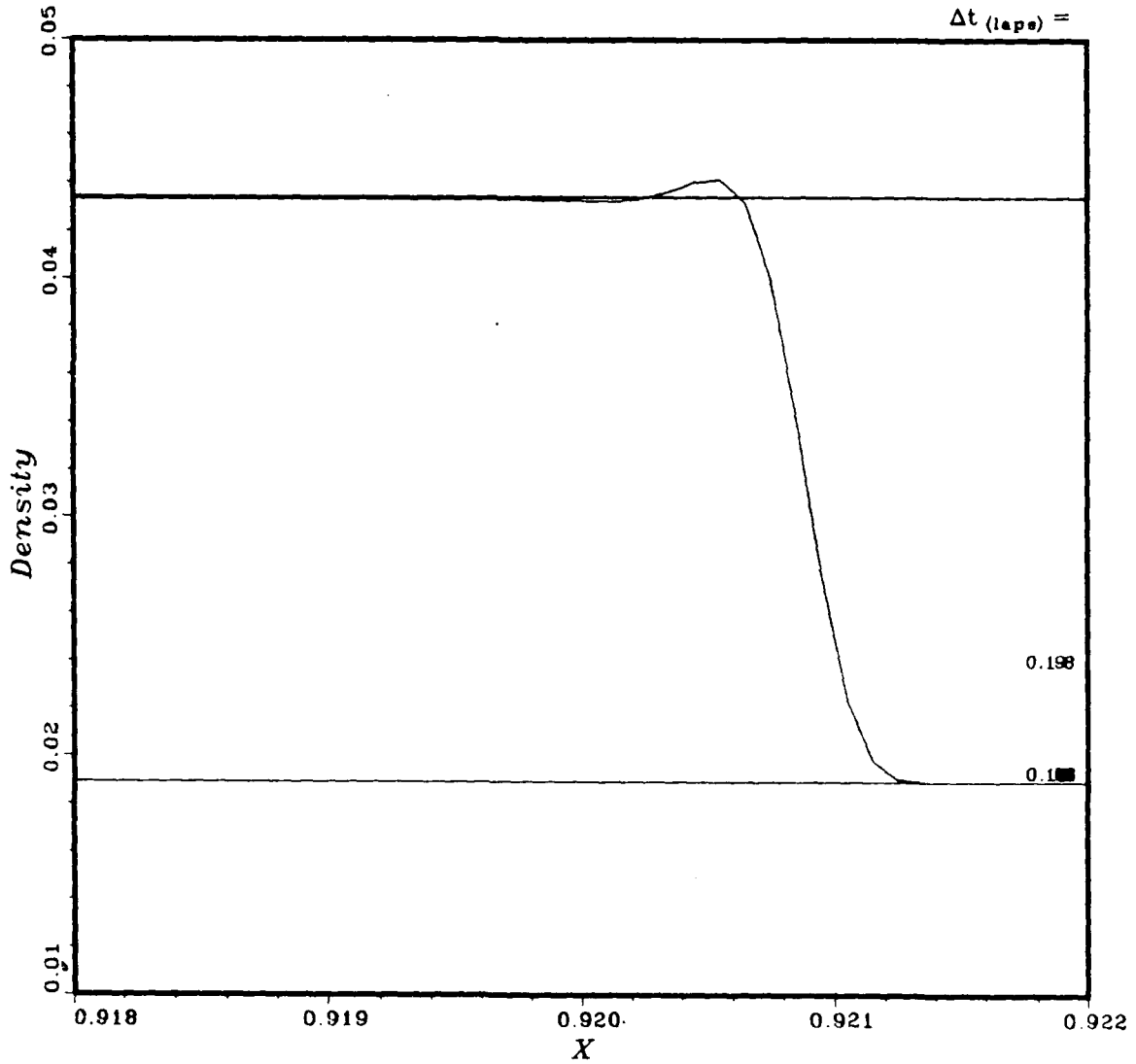


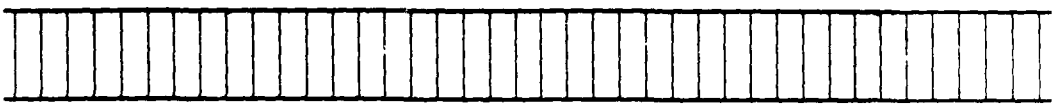
Figure 11. Shock front detail, density versus distance, case 1, zero opening time

PLOT 6 08.19.19 THUR 10 DEC, 1987 JOB-PID30086, ISSCO DISSPLA 10.0

velocity

CASE~ 1n: BRL1 - PLOT 3
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.935, 0.938, 0.940



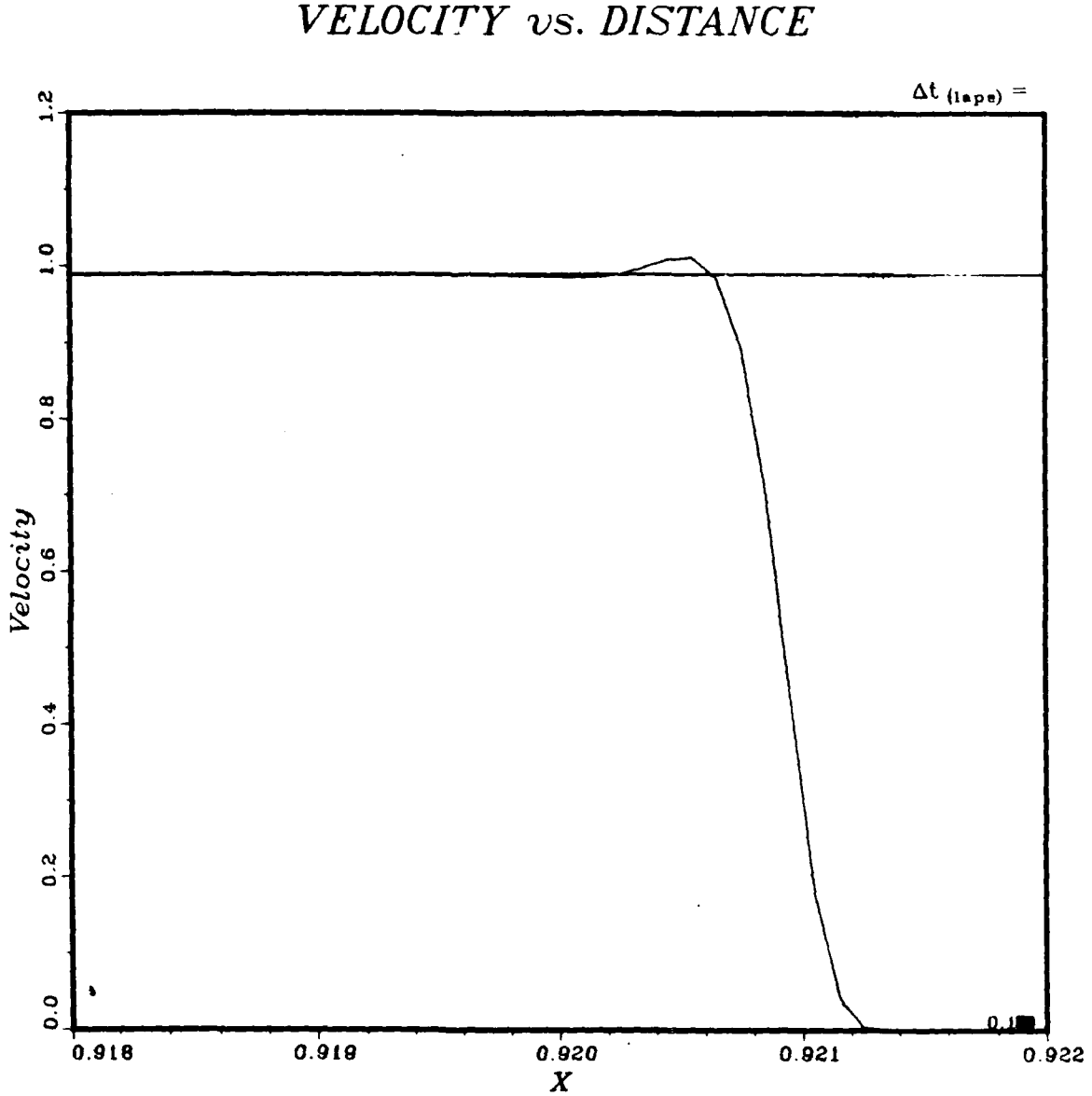


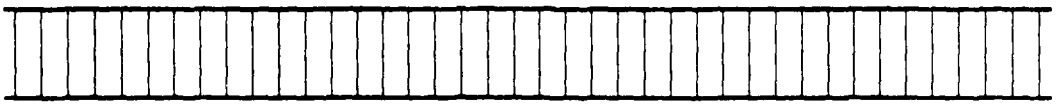
Figure 12. Shock front detail, velocity versus distance, case 1, zero opening time

PLOT 9 08.19.29 THUR 10 DEC, 1987 JOB-P1030086, ISSCO DISPLA 10.0

sound speed

CASE~ 1n: BRL1 – PLOT 3
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1933. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.935, 0.938, 0.940



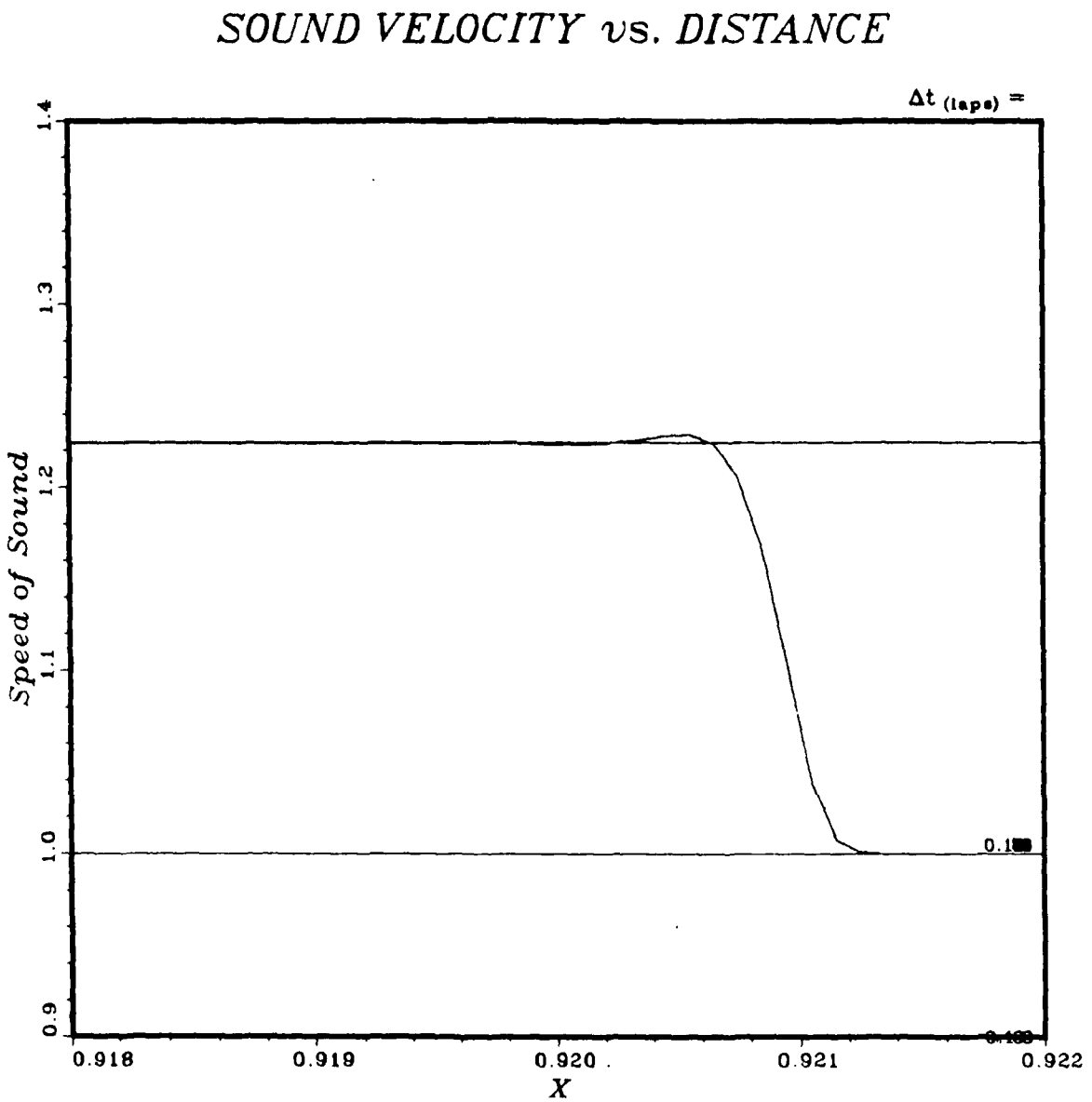


Figure 13. Shock front detail, sound speed versus distance, case 1, zero opening time

PLOT 12 08.19.40 THUR 10 DEC, 1987 JOB=P10300B6, ISSCO DISSPLA 10.0

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 1n: BRL1			P-so	= 254.6 kPa	(36.92 psi)
L-ref	= 200.0 m	X-sta	= 97.50 m	t-a	= 175.5 ms	
L-drv	= 80.00 m	P-drv	= 118.0 atm	PPD	= 0.023 s	(0.083 s)
V-drv	= 1933. m^3	P-amb	= 101.3 kPa	I-so	= 5.586 kPa-s	(0.171 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 168.1 kPa	
L-rwe	= 0.000 m	T4/T1	= 2.235	I-dyn	= 3.600 kPa-s	(0.287 kT)

PRESSURE-TIME HISTORY

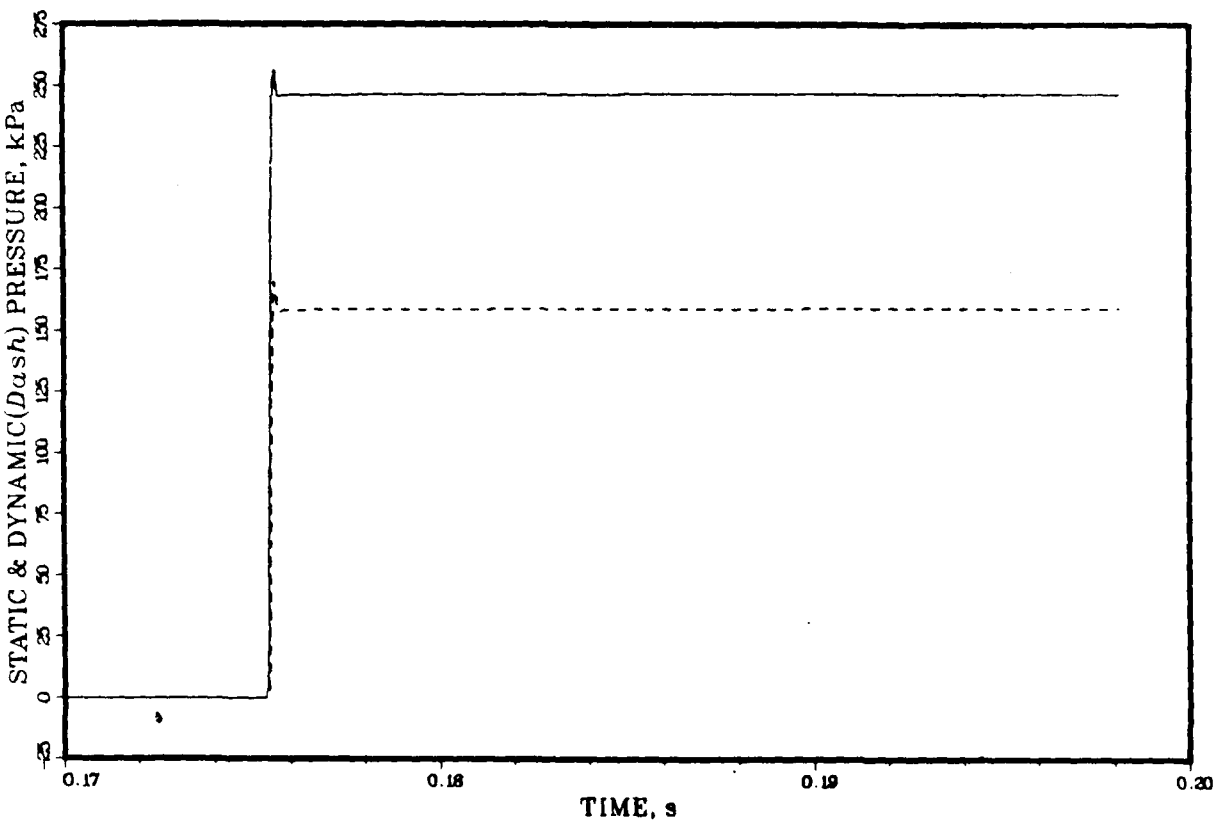


Figure 14. Pressure versus time, case 1, zero opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 1n: BRL1			P-so	= 254.6 kPa	(36.92 psi)
L-ref	= 200.0 m	X-sta	= 97.50 m	t-a	= 175.5 ms		
L-drv	= 80.00 m	P-drv	= 118.0 atm	PPD	= 0.023 s	(0.083 s)
V-drv	= 1933. m^3	P-amb	= 101.3 kPa	I-so	= 5.586 kPa-s	(0.171 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 168.1 kPa	
L-rwe	= 0.000 m	T4/T1	= 2.235	I-dyn	= 3.600 kPa-s	(0.287 kT)

PRESSURE-TIME HISTORY

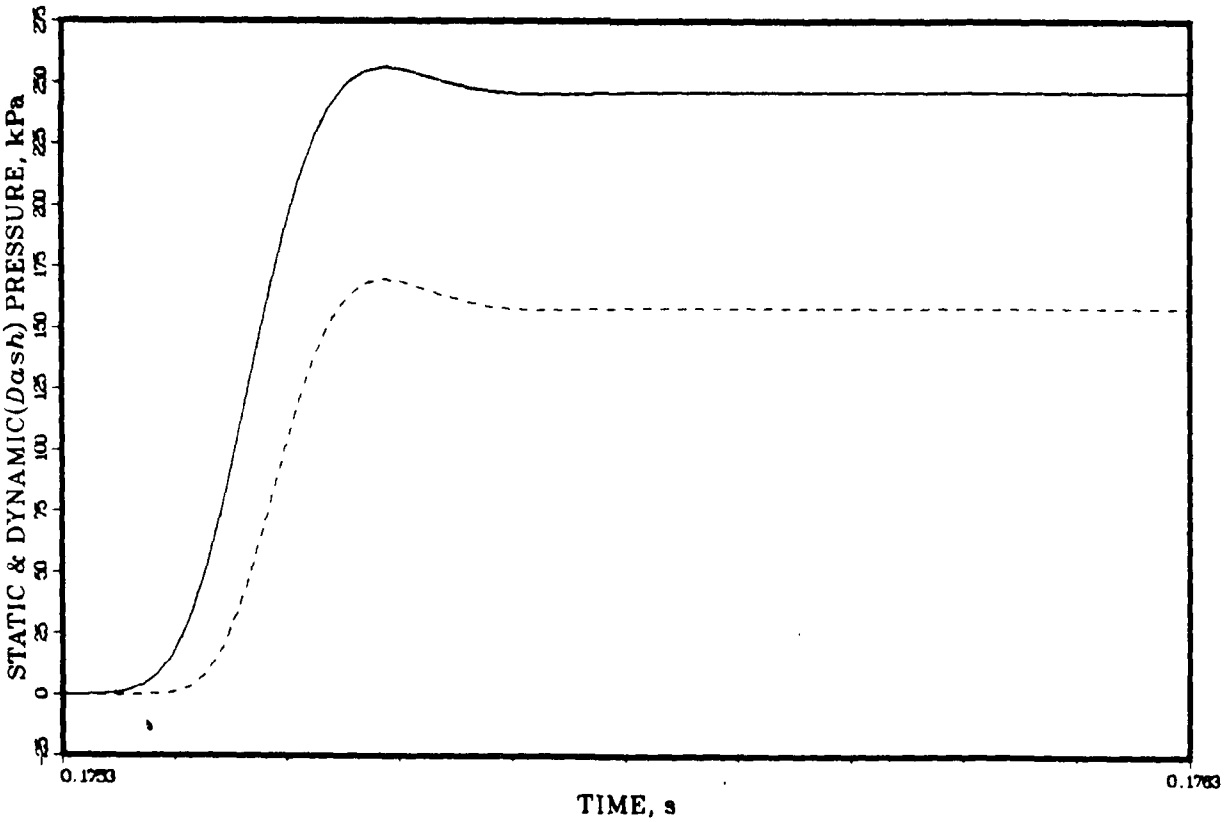


Figure 15. Detail, pressure versus time, case 1, zero opening time

PLOT 2 09.34.58 THUR 10 DEC, 1987 JOB-PI038060, ISSCO DISSPLA 10.0

pressure

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 1.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

PRESSURE vs. DISTANCE

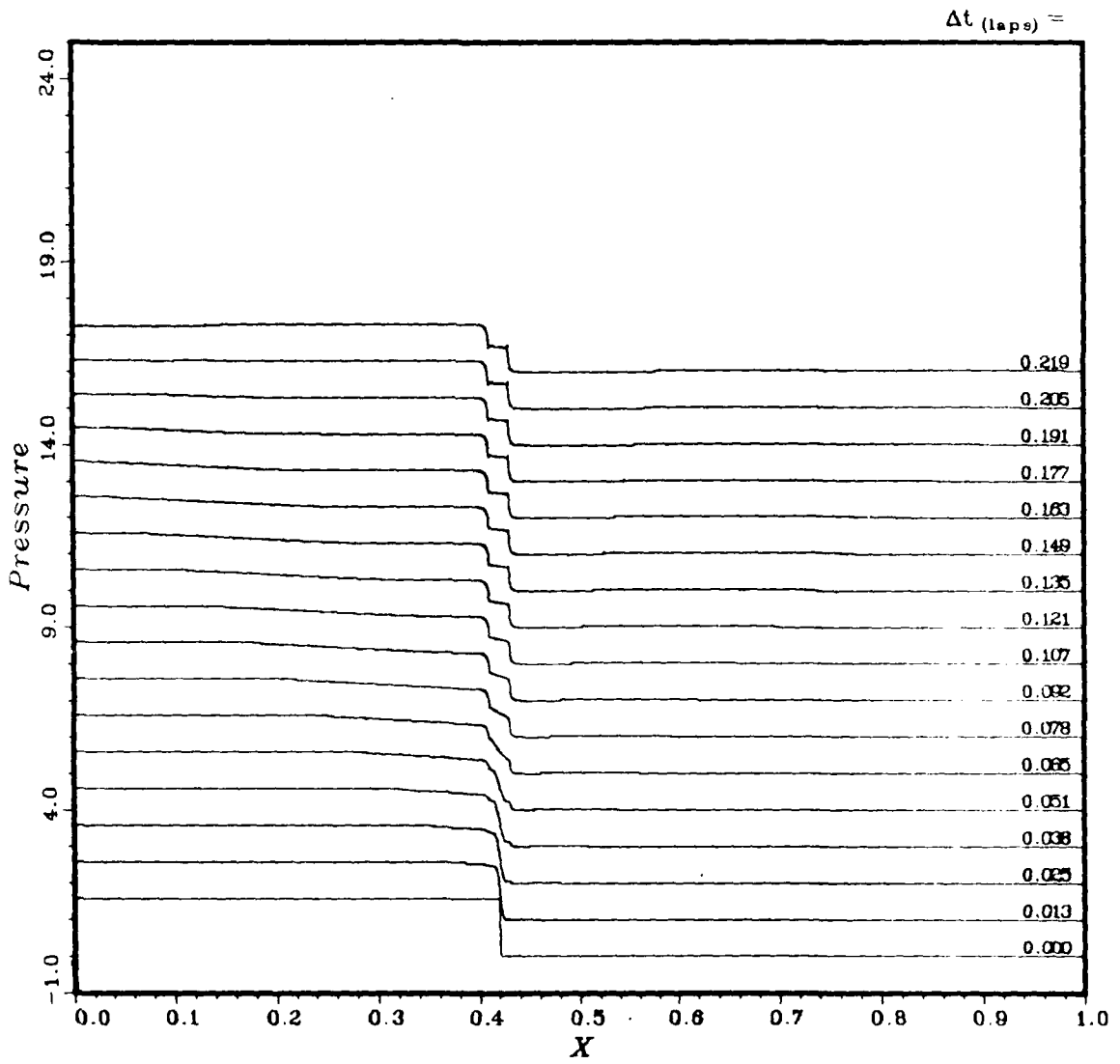


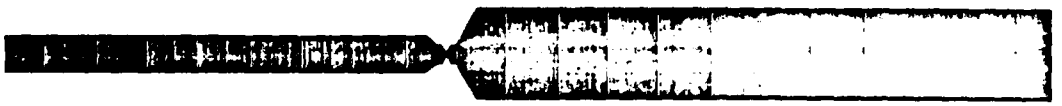
Figure 16. Pressure versus distance, case 1, 65ms opening time

PLOT 2 14.42.57 THUR 14 JAN, 1988 JOB-[illegible], ISSCO DISSPLA 10.0

pressure

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 0.020

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938



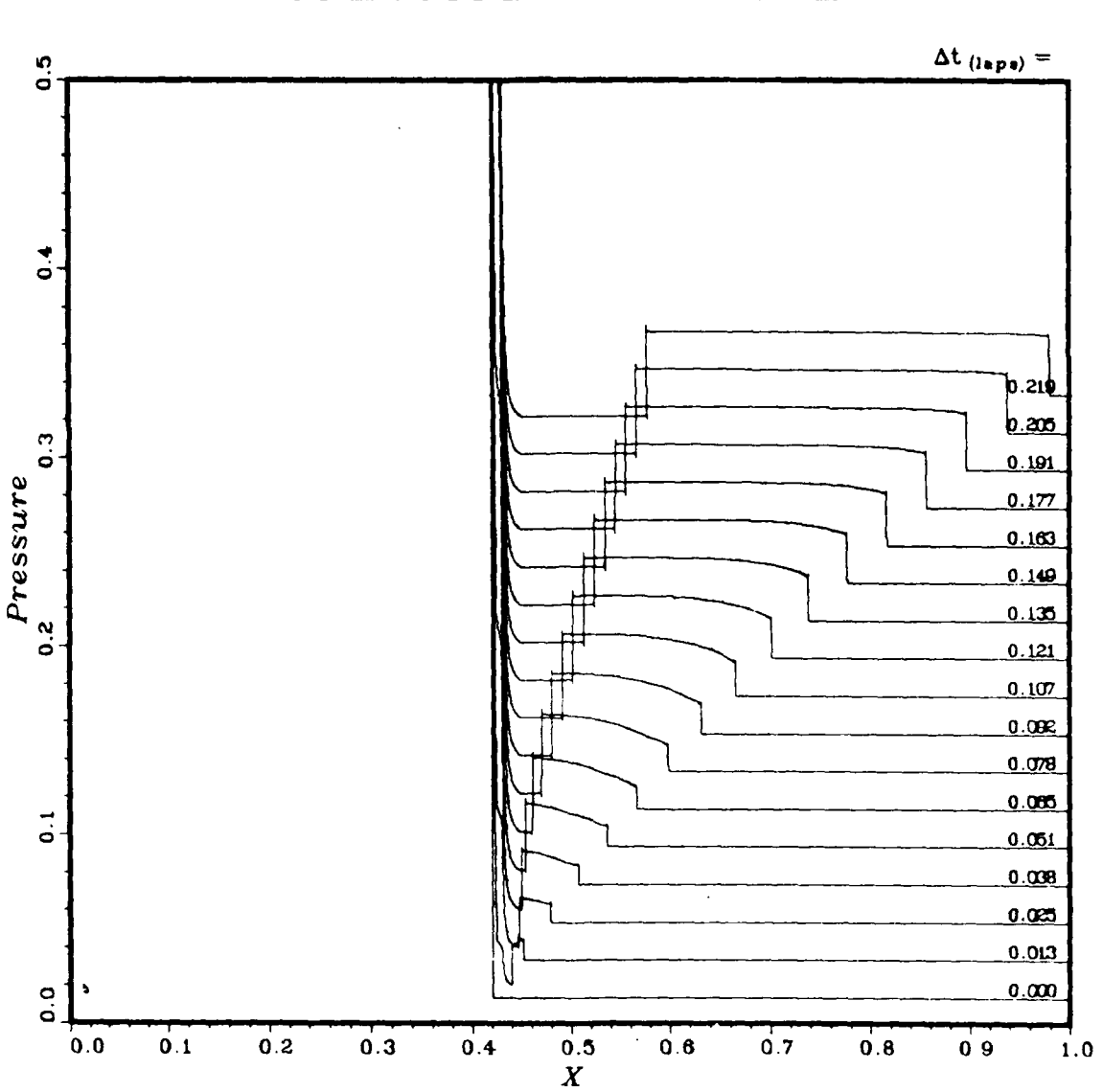


Figure 17. Magnified pressure versus distance, case 1, 65ms opening time

PLOT 1 14.42.36 THUR 14 JAN, 1988 JOB-P1059900, ISSCO GISSPLR 10.0

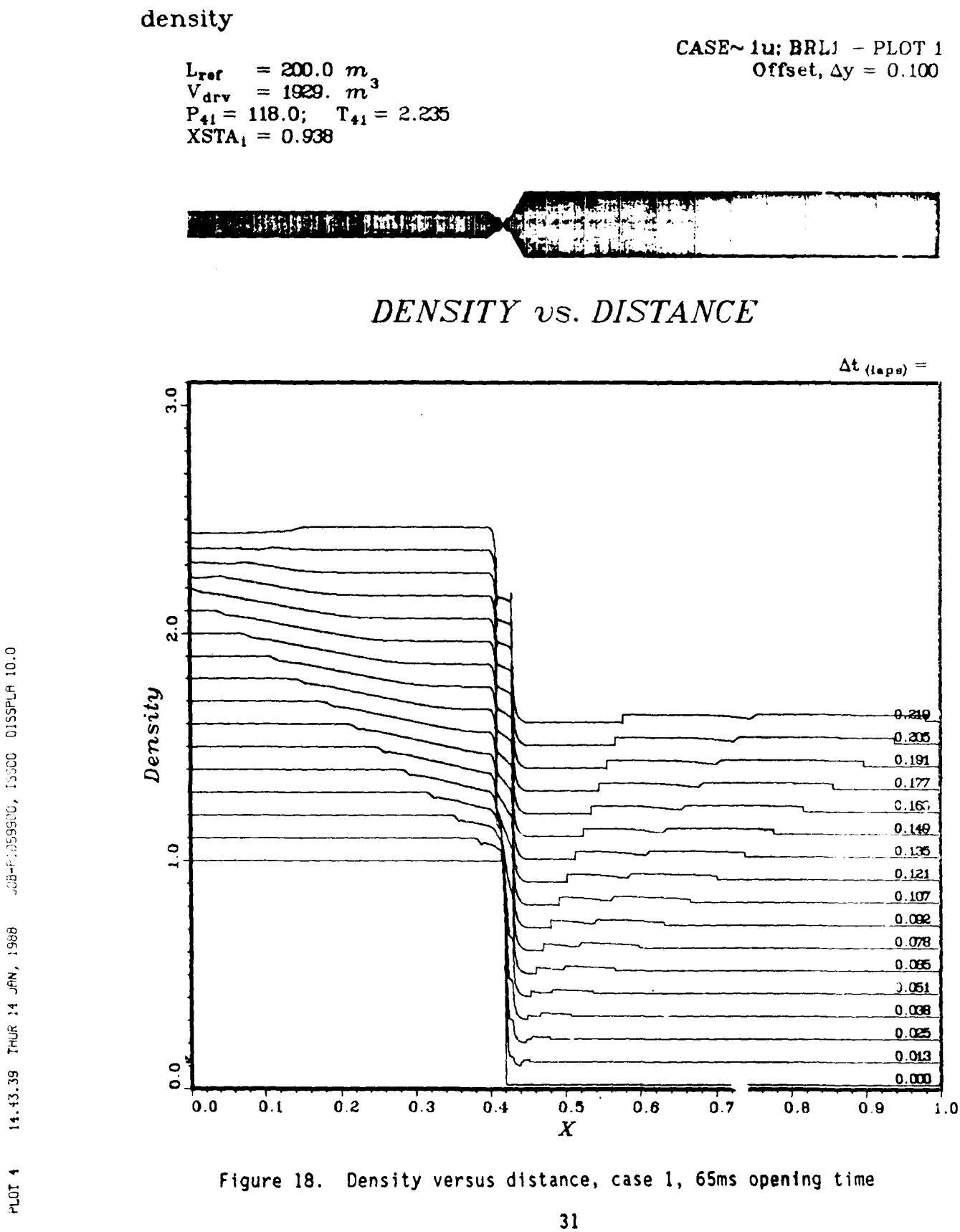


Figure 18. Density versus distance, case 1, 65ms opening time

density

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 0.010

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

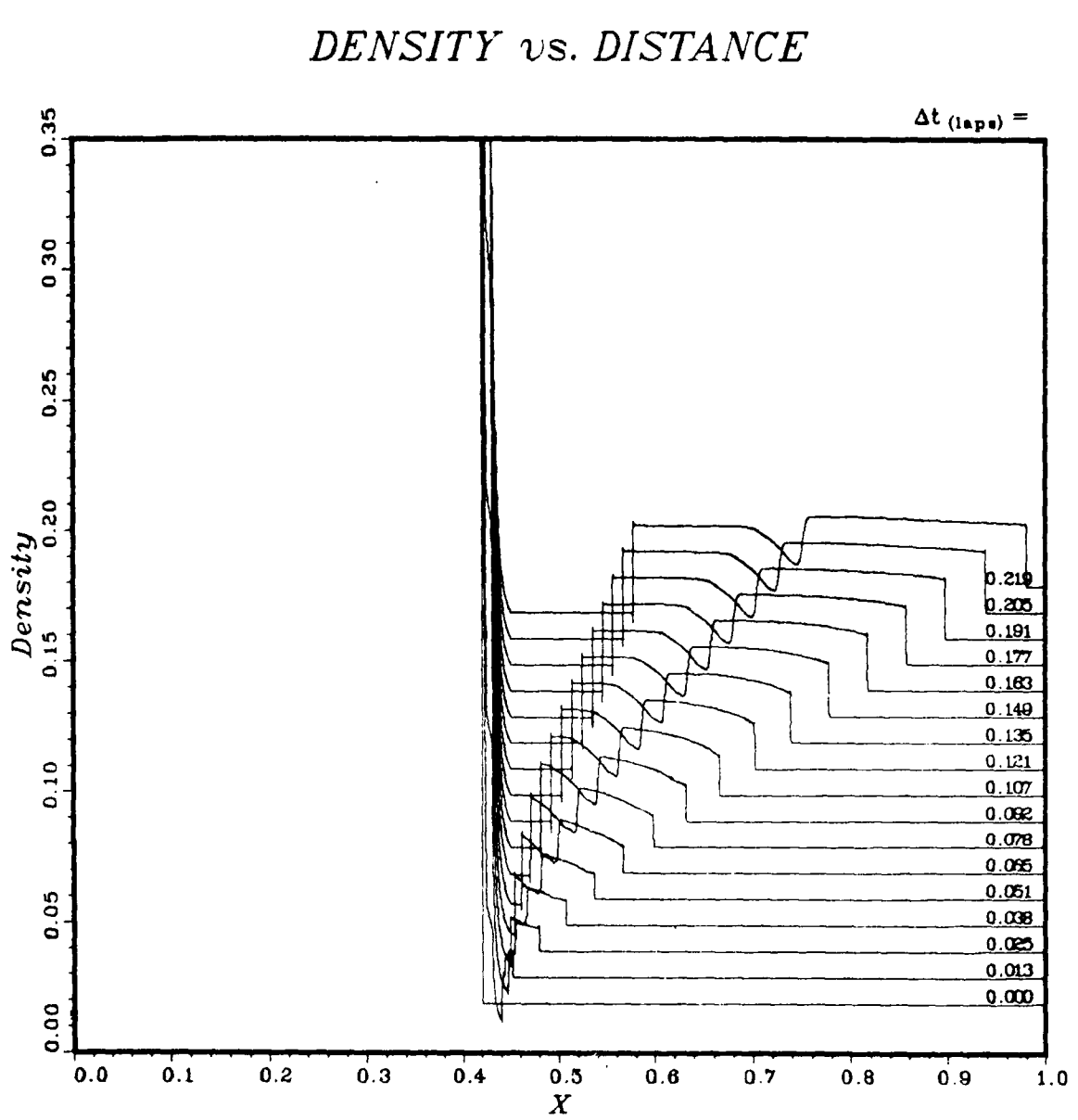


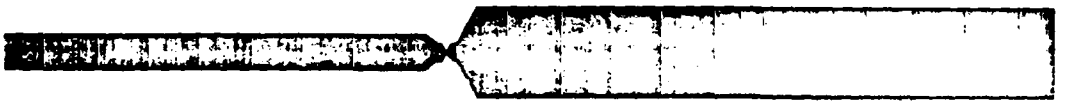
Figure 19. Magnified density versus distance, case 1, 65ms opening time

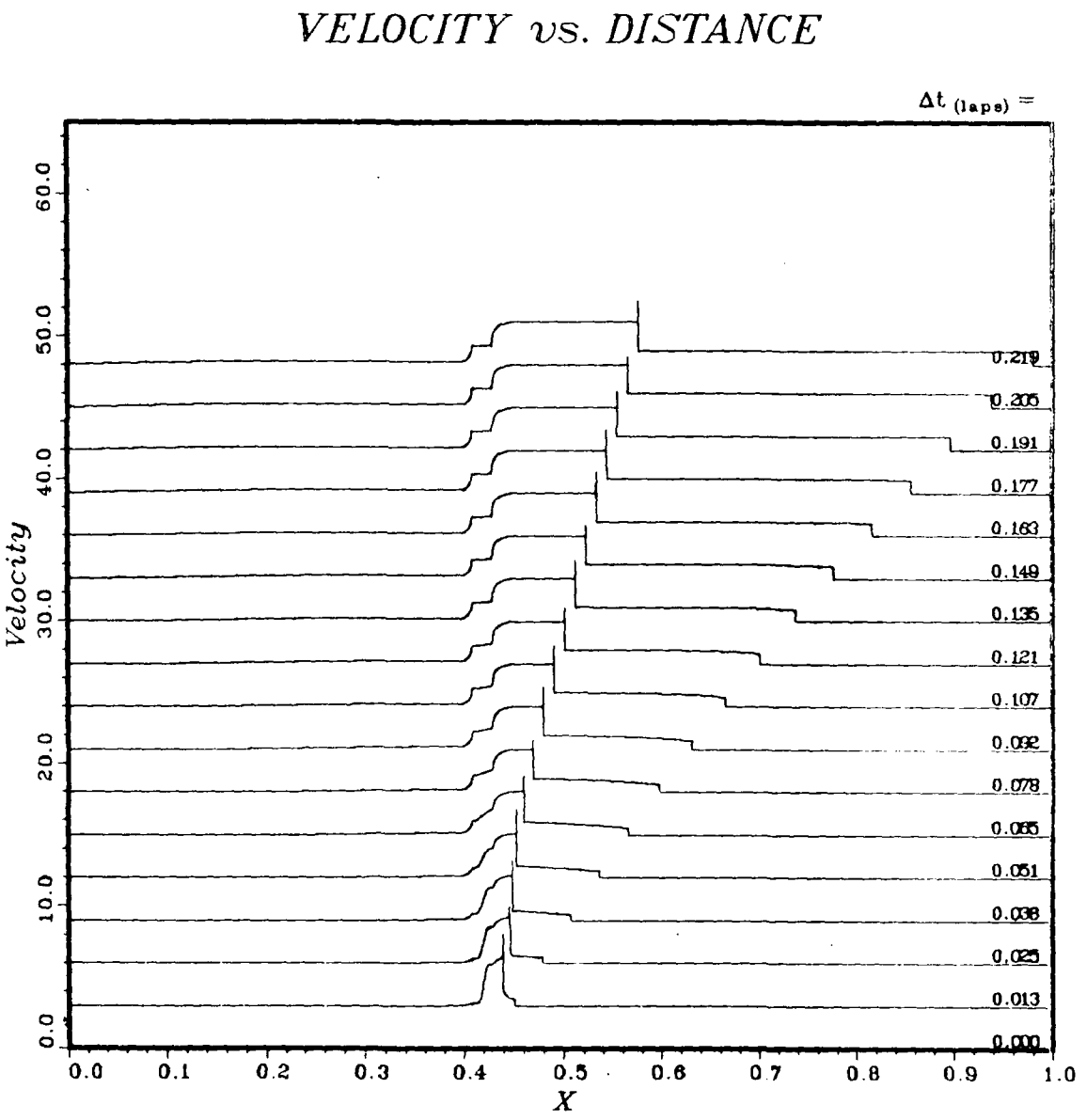
PLOT 3 14.43.14 THUR 14 JAN, 1988 JOB-P1059900, ISSCO DISSPLA 10.0

velocity

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 3.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_i$ = 0.938





PLOT 6 14.44.16 THUR 14 JAN, 1988 JCB-PIDS9900, ISSCO DISSPLA 10.0

Figure 20. Velocity versus distance, case 1, 65ms opening time

velocity

CASE~ 1u: BRL1 – PLOT :
Offset, Δy = 0.200

L_{ref} = 200.0 m
$\forall_{drv}$ = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

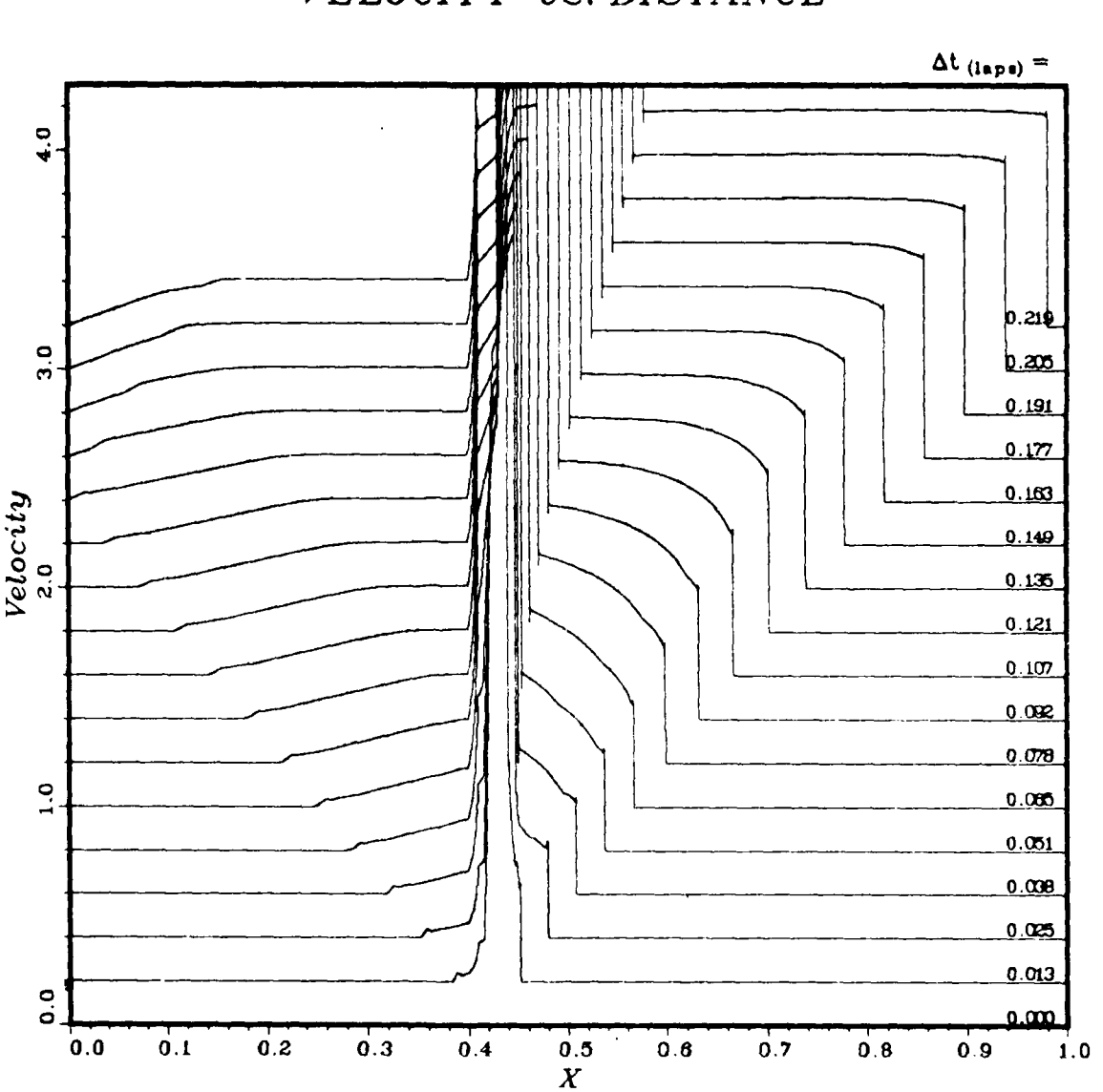


Figure 21. Magnified velocity versus distance, case 1, 65ms opening time

PLOT 5 14.43.57 THUR 14 JAN, 1988 JOB-P1059900, ISSCO DISSPLA 10.0

sound speed

CASE~ 1u: BRL1 - PLOT 1
Offset, Δy = 1.500

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

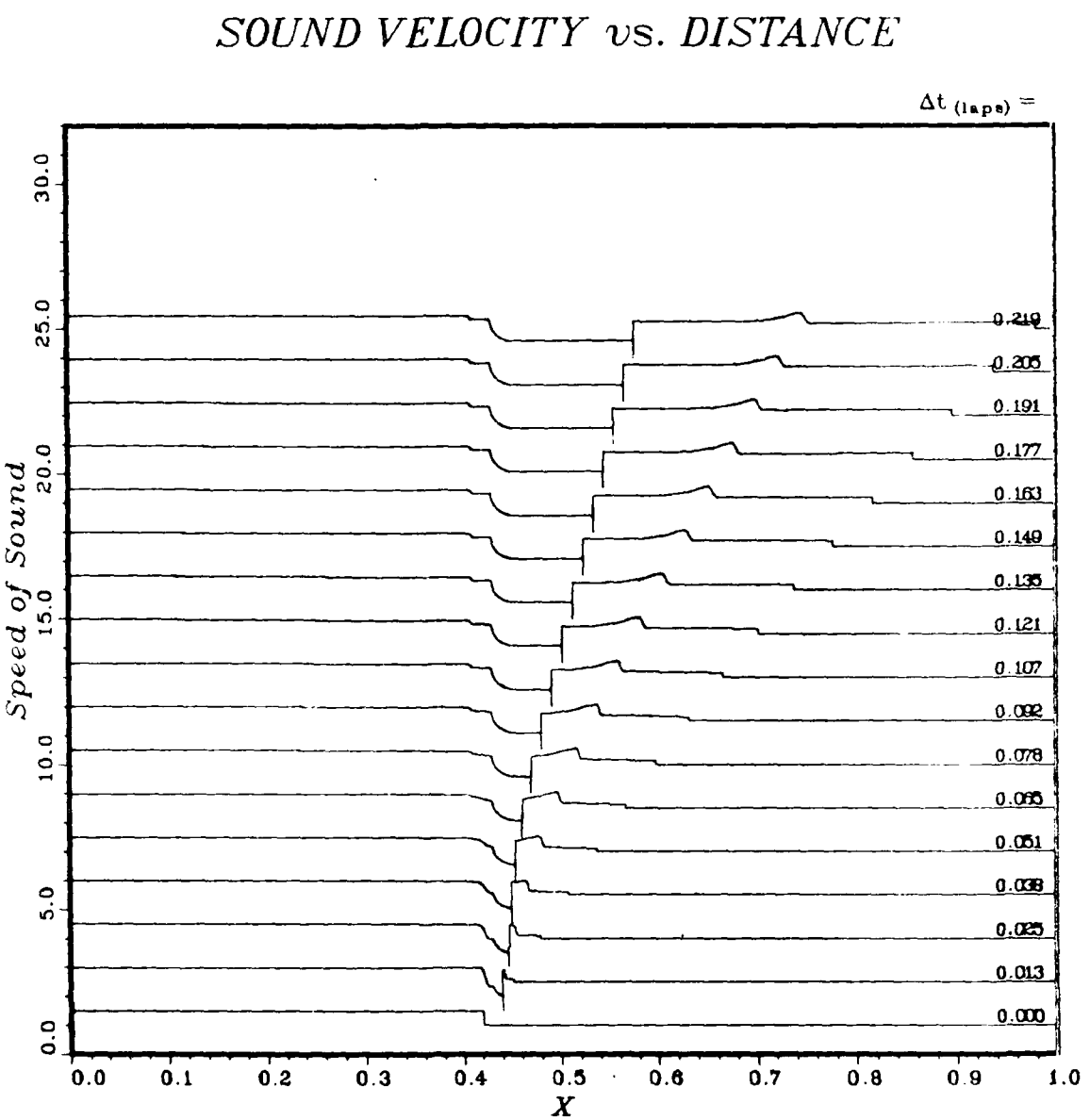


Figure 22. Sound speed versus distance, case 1, 65ms opening time

PLOT 7 14.44.59 THUR 14 JAN, 1988 JOB-F1059900, ISSCO DISSPLA 10.0

sound speed

CASE~ 1u: BRL1 - PLOT 1
Offset, Δy = 0.030

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.635
$XSTA_1$ = 0.938

SOUND VELOCITY vs. DISTANCE

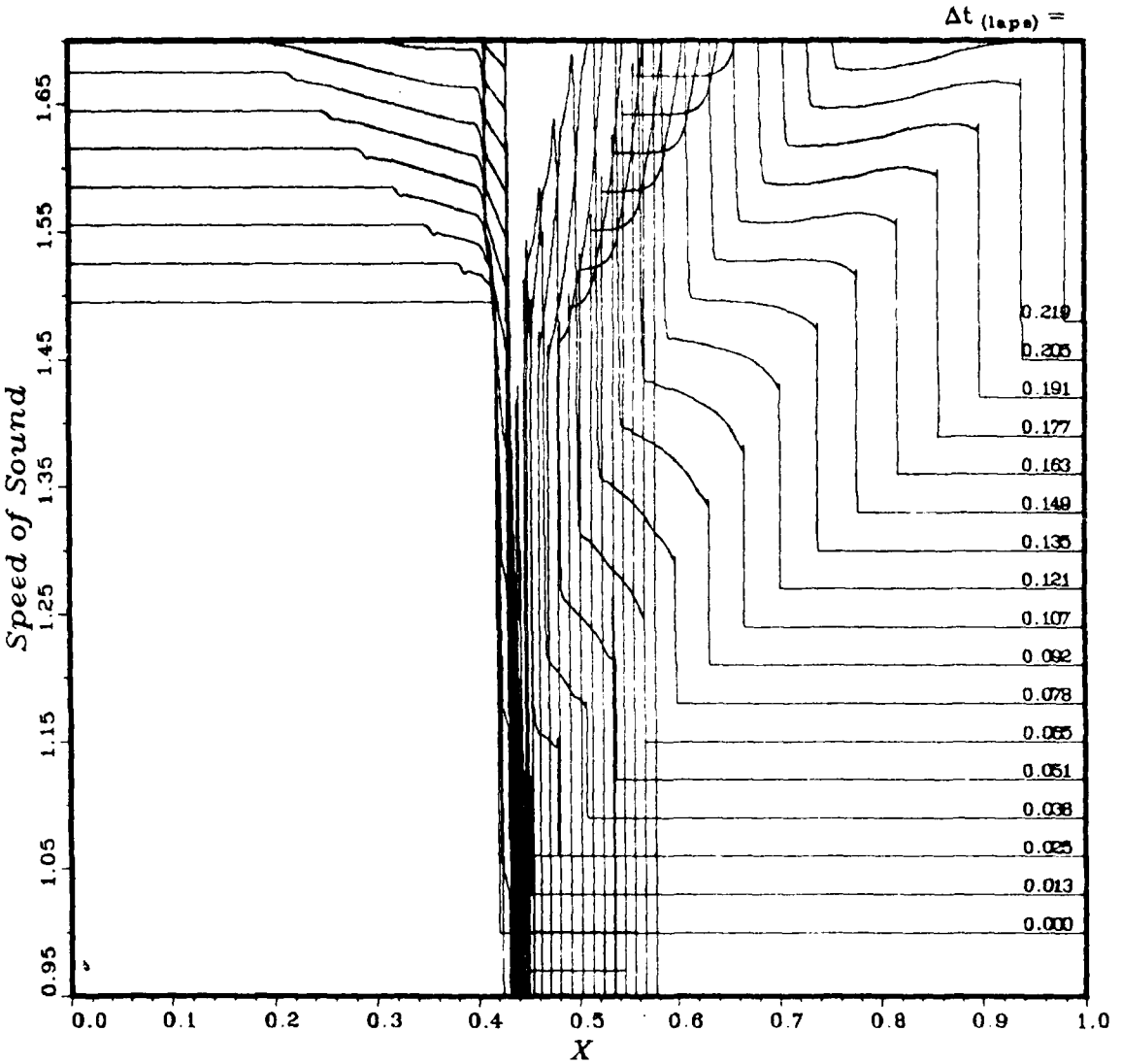


Figure 23. Magnified sound speed versus distance, case 1, 65ms opening time

PLOT 7 14.44.33 THUR 14 JAN, 1988 JOB-P1059900, ISSCO DISSPLA 10.0

pressure

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

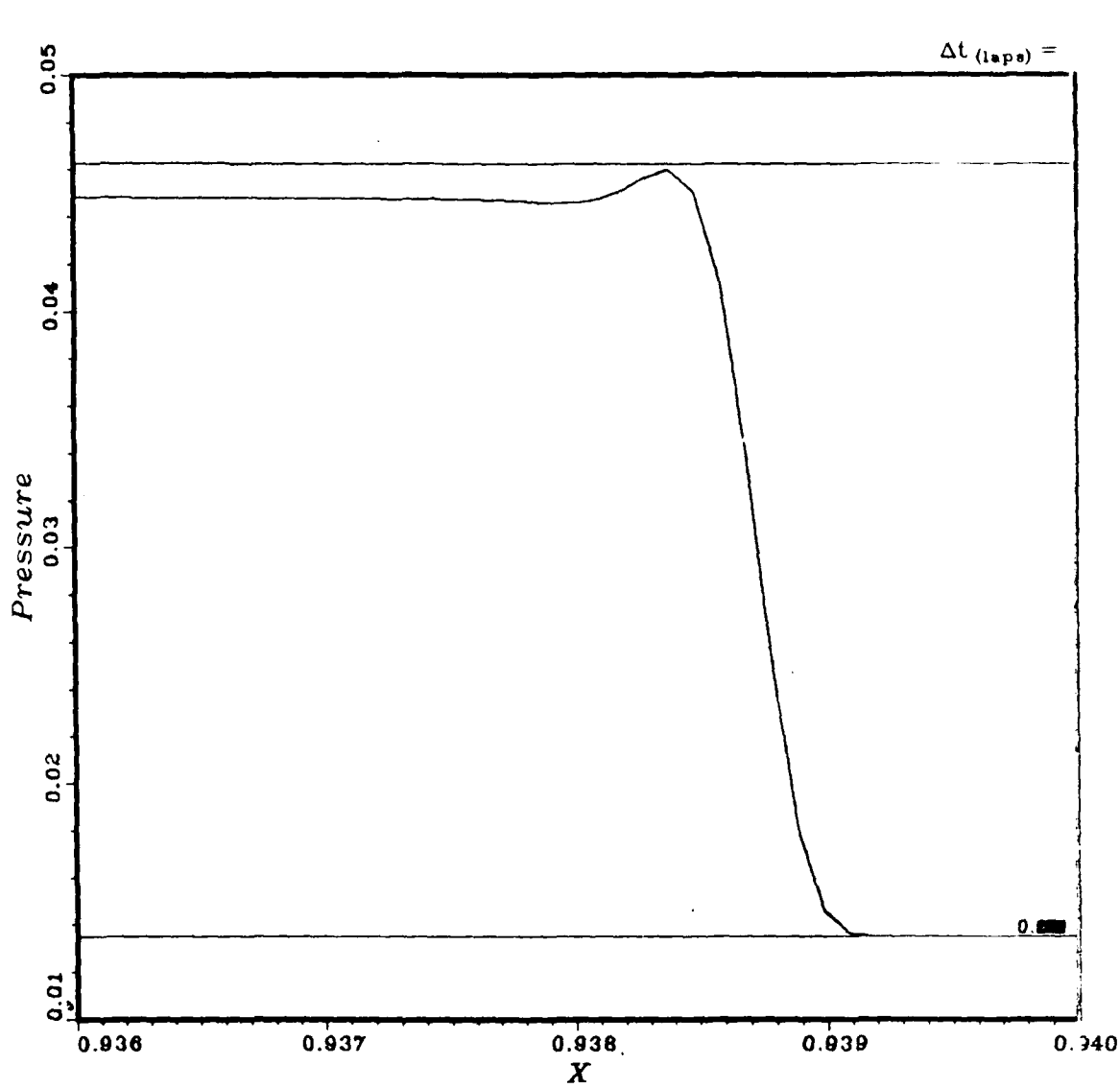


Figure 24. Shock front detail, pressure versus distance, case 1, 65ms opening time

PLOT 1 15.41.52 THUR 14 JAN, 1988 JOB-PID63148, ISSCO DISSPLA 10.0

density

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

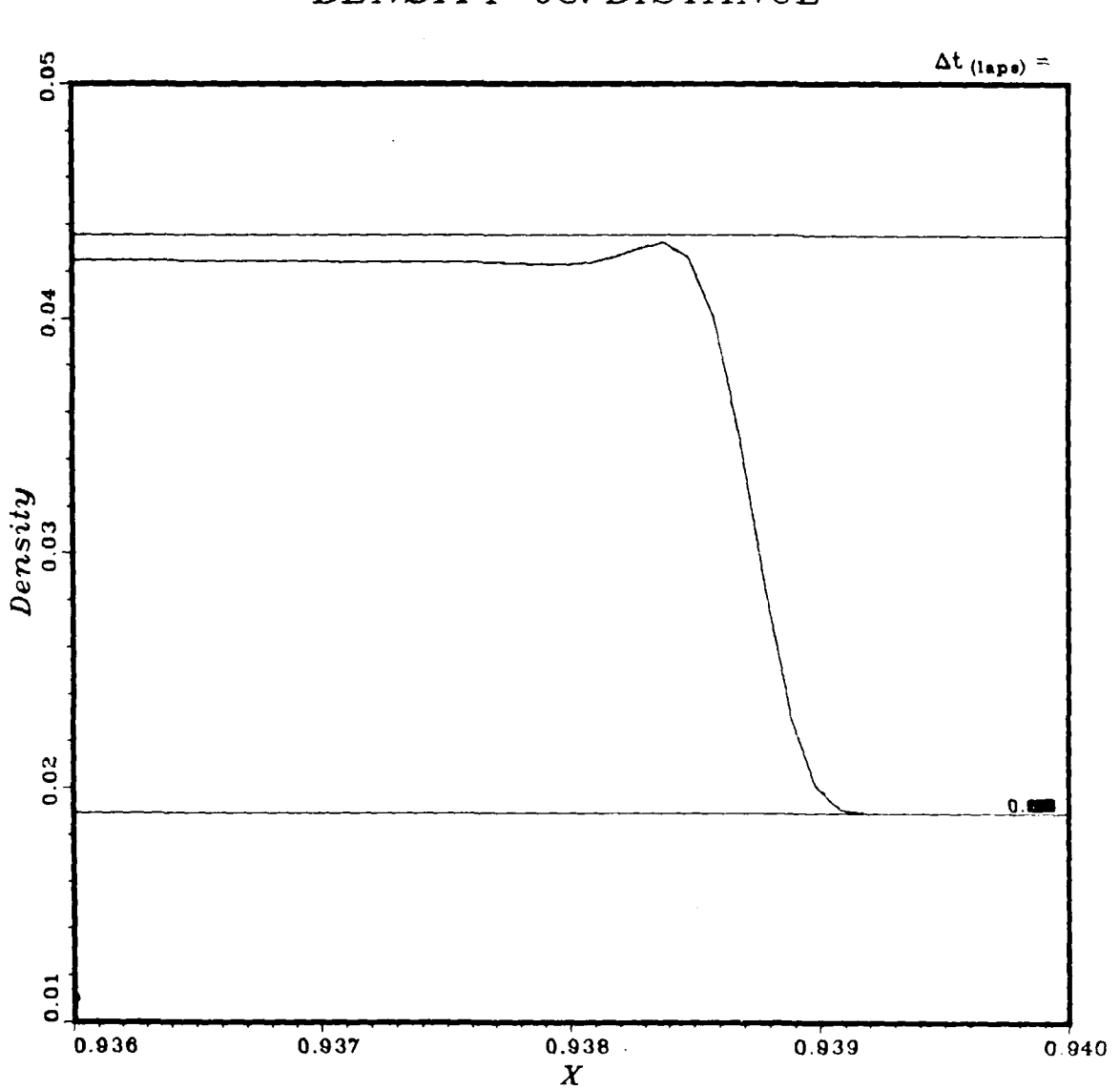


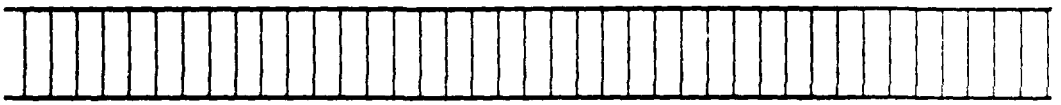
Figure 25. Shock front detail, density versus distance, case 1, 65ms opening time

PLOT 2 15.44.59 THUR 14 JAN, 1988 JOB-PID63148, ISSCO DISSPLA 10.0

velocity

CASE~ 1u: BRL1 – PLOT 1
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938



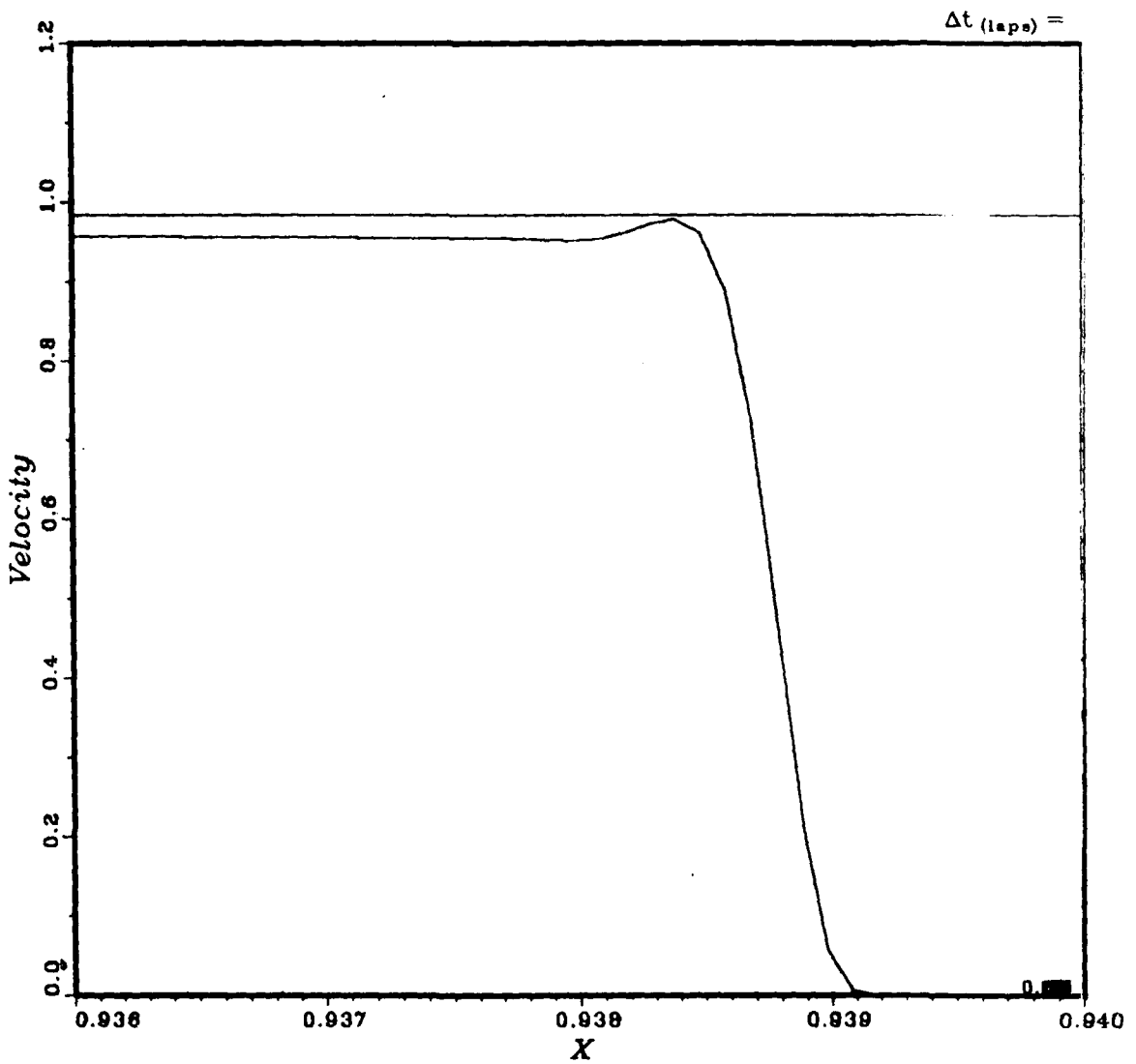


Figure 26. Shock front detail, velocity versus distance, case 1, 65ms opening time

PLOT 3 15.45.07 THUR 14 JAN, 1988 JOB-PID63148, ISSCO DISSPLA 10.0

sound speed

CASE~ 1u: BRL1 - PLOT 1
Offset, Δy = 0.000

L_{ref} = 200.0 m
V_{drv} = 1929. m^3
P_{41} = 118.0; T_{41} = 2.235
$XSTA_1$ = 0.938

SOUND VELOCITY vs. DISTANCE

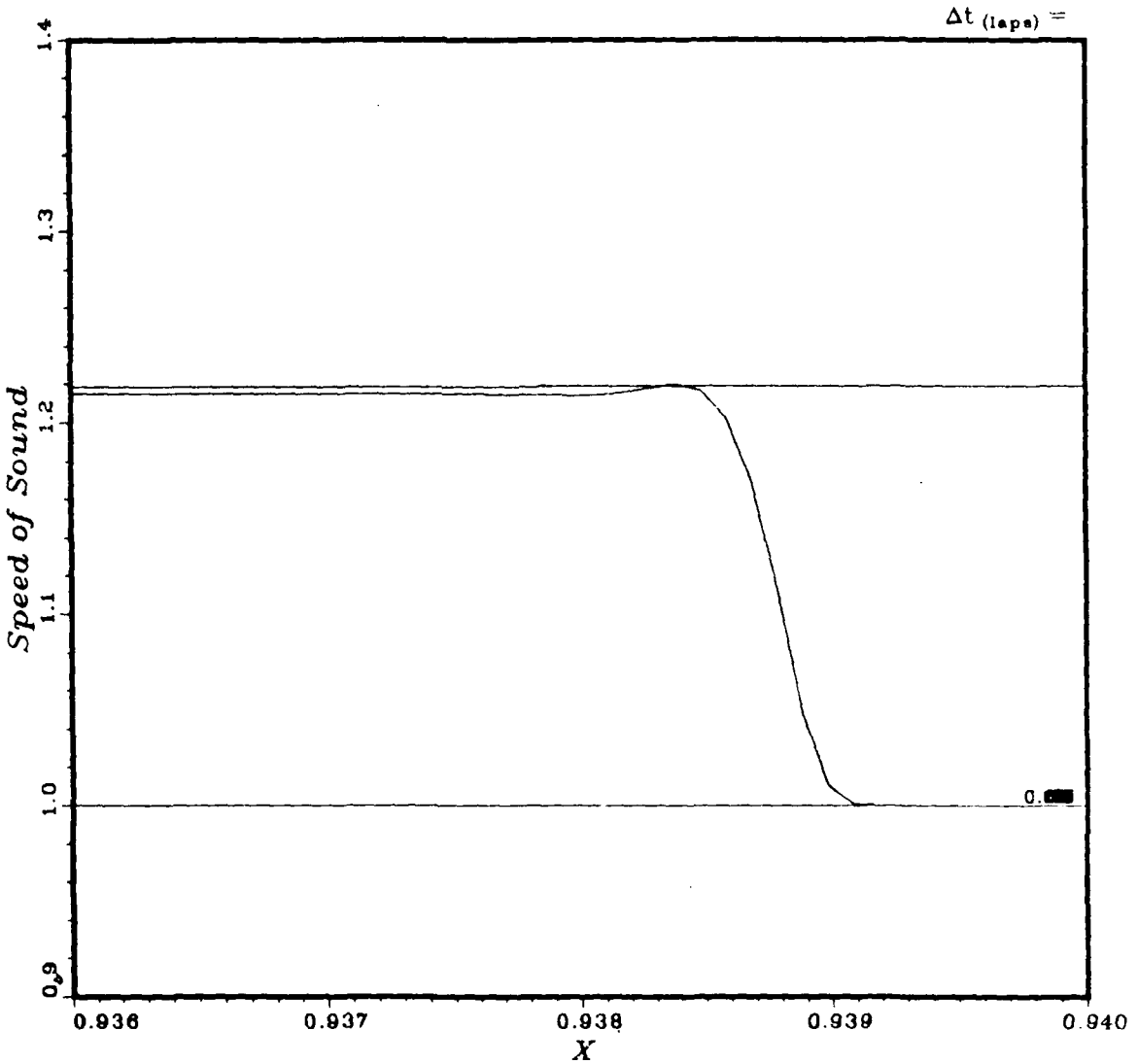


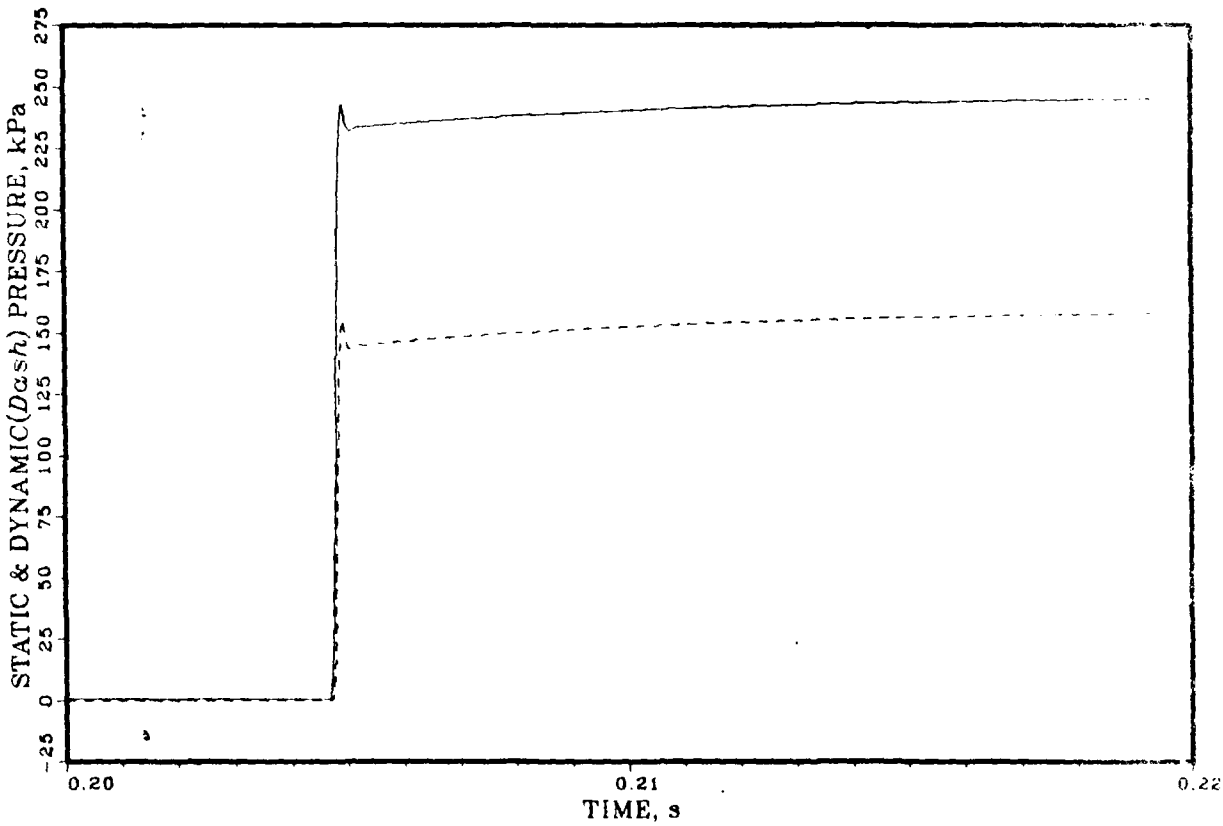
Figure 27. Shock front detail, sound speed versus distance, case 1, 65ms opening time

PLOT 4 15.45.15 THUR 14 JAN, 1988 JOB-P1D63148, ISSCO DISSPLA 10.0

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 1u: BRL1			P-so	= 241.2 kPa	(34.98 psi)
L-ref	= 200.0 m	X-sta	= 97.50 m	t-a	= 204.8 ms	
L-drv	= 80.00 m	P-drv	= 118.0 atm	PPD	= 0.015 s	(0.054 s)
V-drv	= 1929. m^3	P-amb	= 101.3 kPa	I-so	= 3.502 kPa-s	(0.045 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 153.2 kPa	
L-rwc	= 0.000 m	T4/T1	= 2.235	I-dyn	= 2.224 kPa-s	(0.028 kT)

PRESSURE-TIME HISTORY



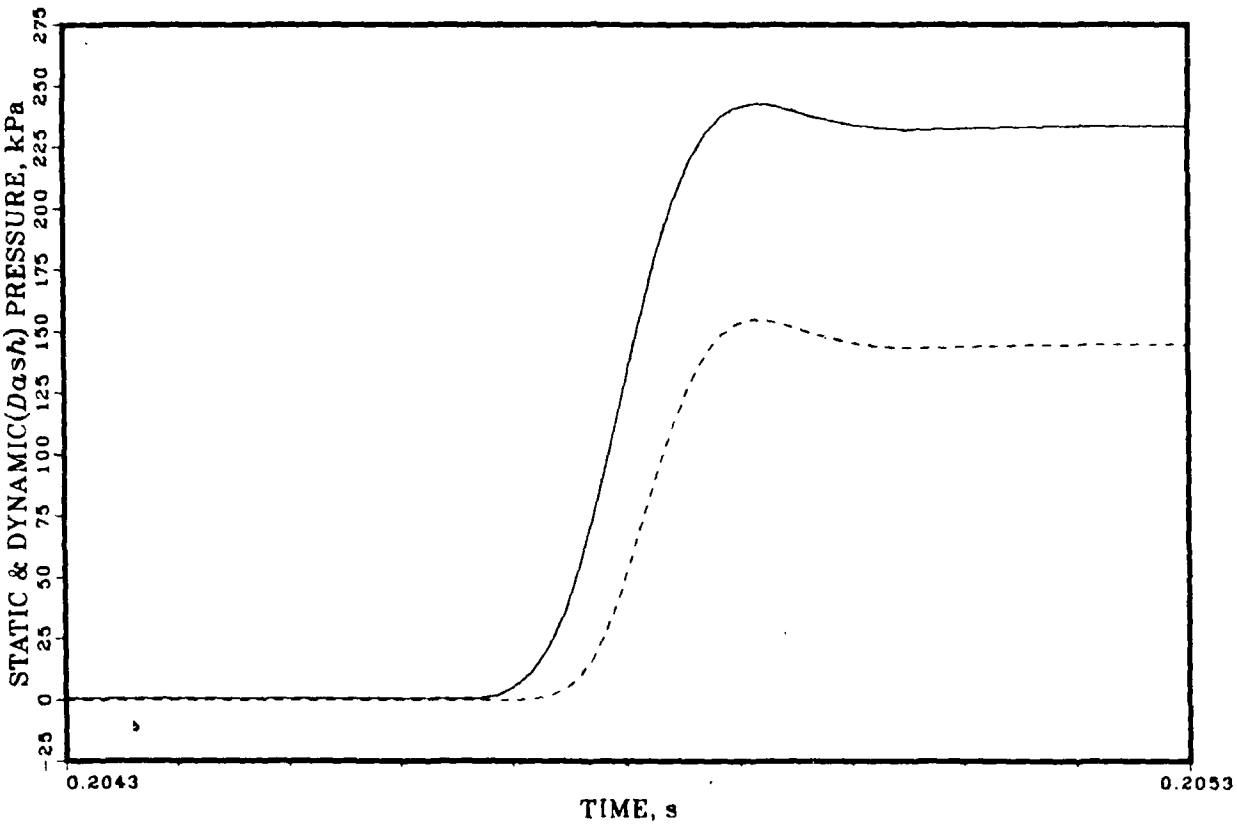
PLOT 1 15:10:56 THUR 14 JUN, 1990 JOB-P1061649, 15000 DISSPLA 10.2

Figure 28. Pressure versus time, case 1, 65ms opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 1u: BRL1			P-so	= 241.2 kPa	(34.98 psi)
L-ref	= 200.0 m	X-sta	= 97.50 m	t-a	= 204.8 ms	
L-drv	= 80.00 m	P-drv	= 118.0 atm	PPD	= 0.015 s	(0.054 s)
V-drv	= 1929. m^3	P-amb	= 101.3 kPa	I-so	= 3.502 kPa-s	(0.045 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 153.2 kPa	
L-rwe	= 0.000 m	T4/T1	= 2.235	I-dyn	= 2.224 kPa-s	(0.082 kT)

PRESSURE–TIME HISTORY



PLOT 1 15.54.21 THUR 14 JAN, 1988 JOB-P1063612, ISSCO DISSPLA 10.0

Figure 29. Detail, pressure versus time, case 1, 65ms opening time

pressure

CASE~ 8q: BRL8 – PLOT 1
Offset, Δy = 1.000

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_i$ = 0.911

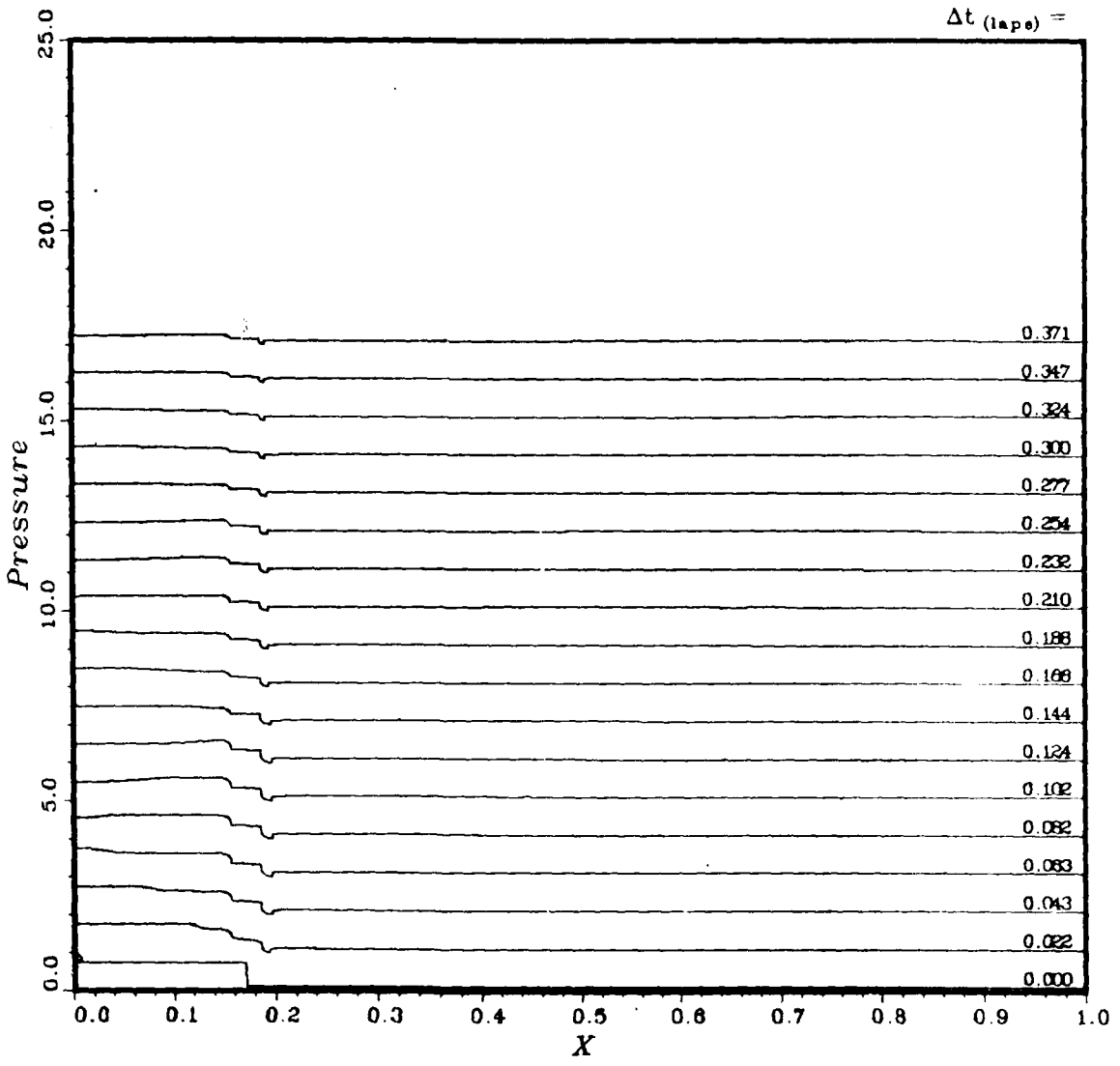


Figure 30. Pressure versus distance, case 8, zero opening time

PLOT 2 03.04.36 FRI 8 JAN, 1988 JOB=P1057385, ISSCO DISSPLA 10.0

pressure

CASE~ 8q: BRL8 – PLOT 1
Offset, Δy = 0.020

L_{ref} = 140.(m
V_{drv} = 512.(m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_i$ = 0.911

PRESSURE vs. DISTANCE

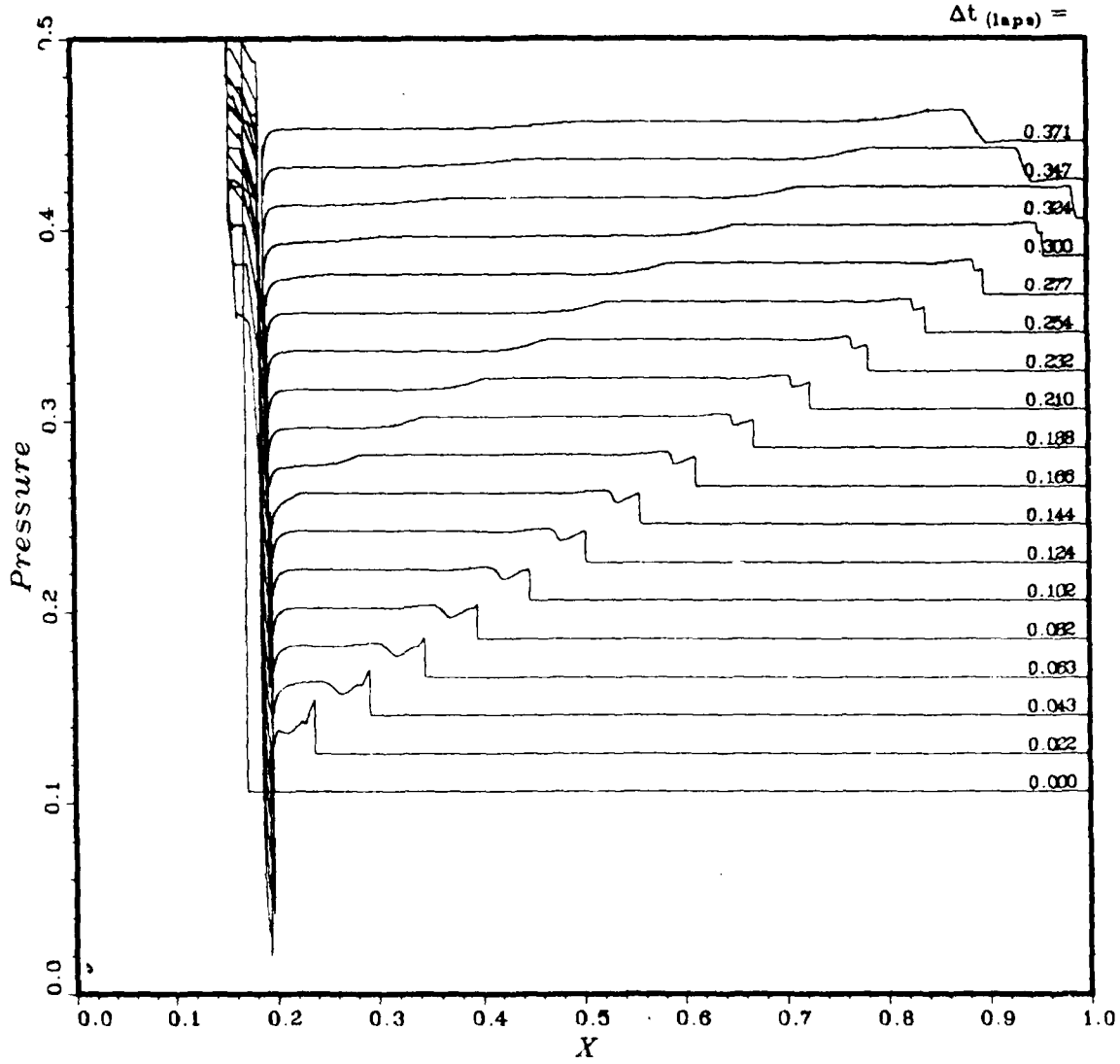


Figure 31. Magnified pressure versus distance, case 8, zero opening time

PLOT 1 03.03.53 FRI 8 JAN, 1988 JOB-P1057385, ISSCO DISSPLA 10.0

density

CASE~ 8q: BRL8 PLOT 1
Offset, Δy = 0.100

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_i$ = 0.911

DENSITY vs. DISTANCE

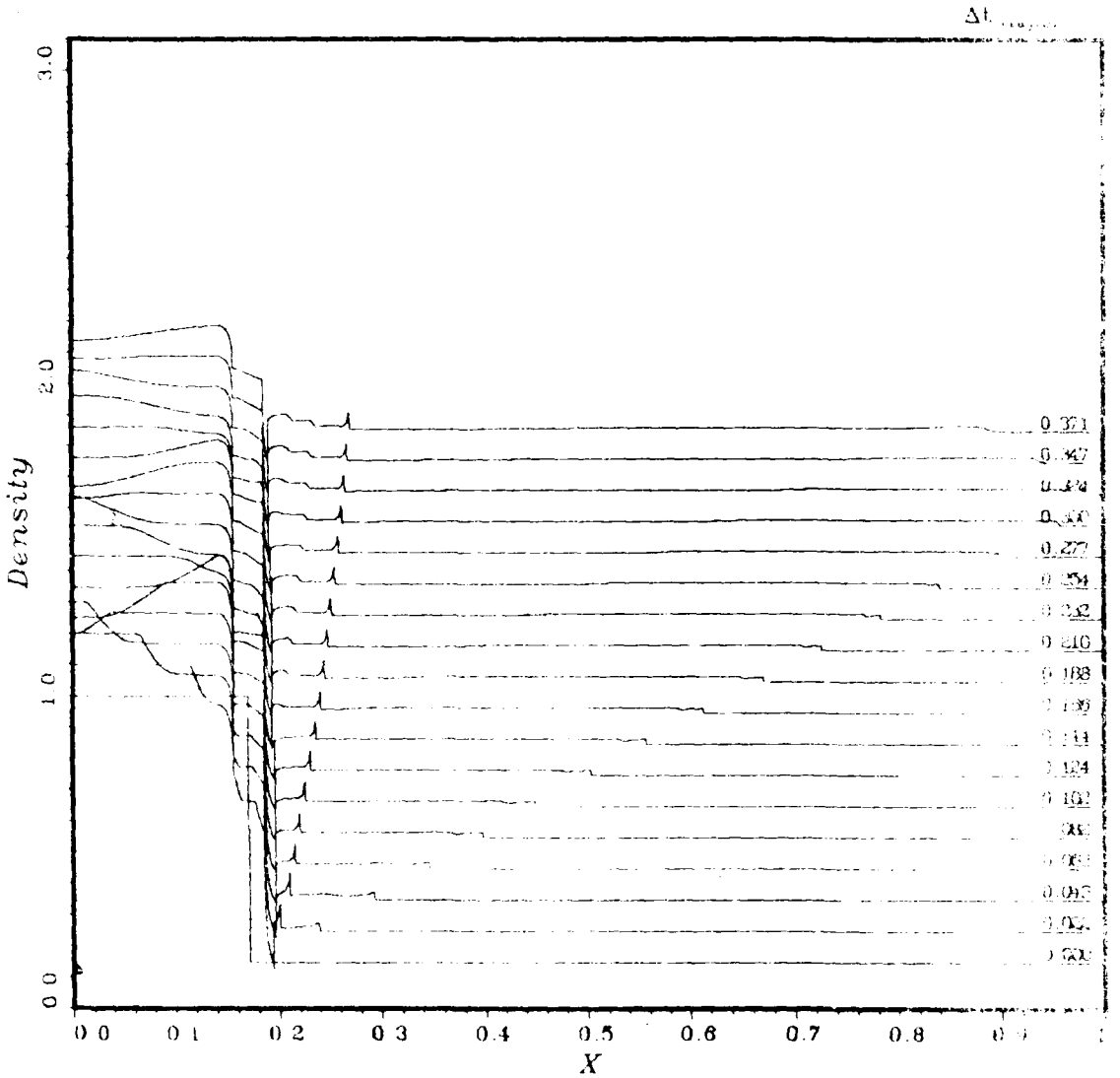
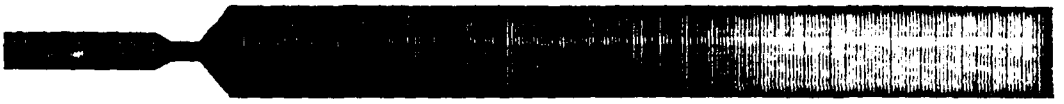


Figure 32. Density versus distance, case 8, zero opening time

density

CASE~ 8q: BRL8 PLOT 1
Offset, Δy = 0.0 0.0

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_1$ = 0.911



DENSITY vs. DISTANCE

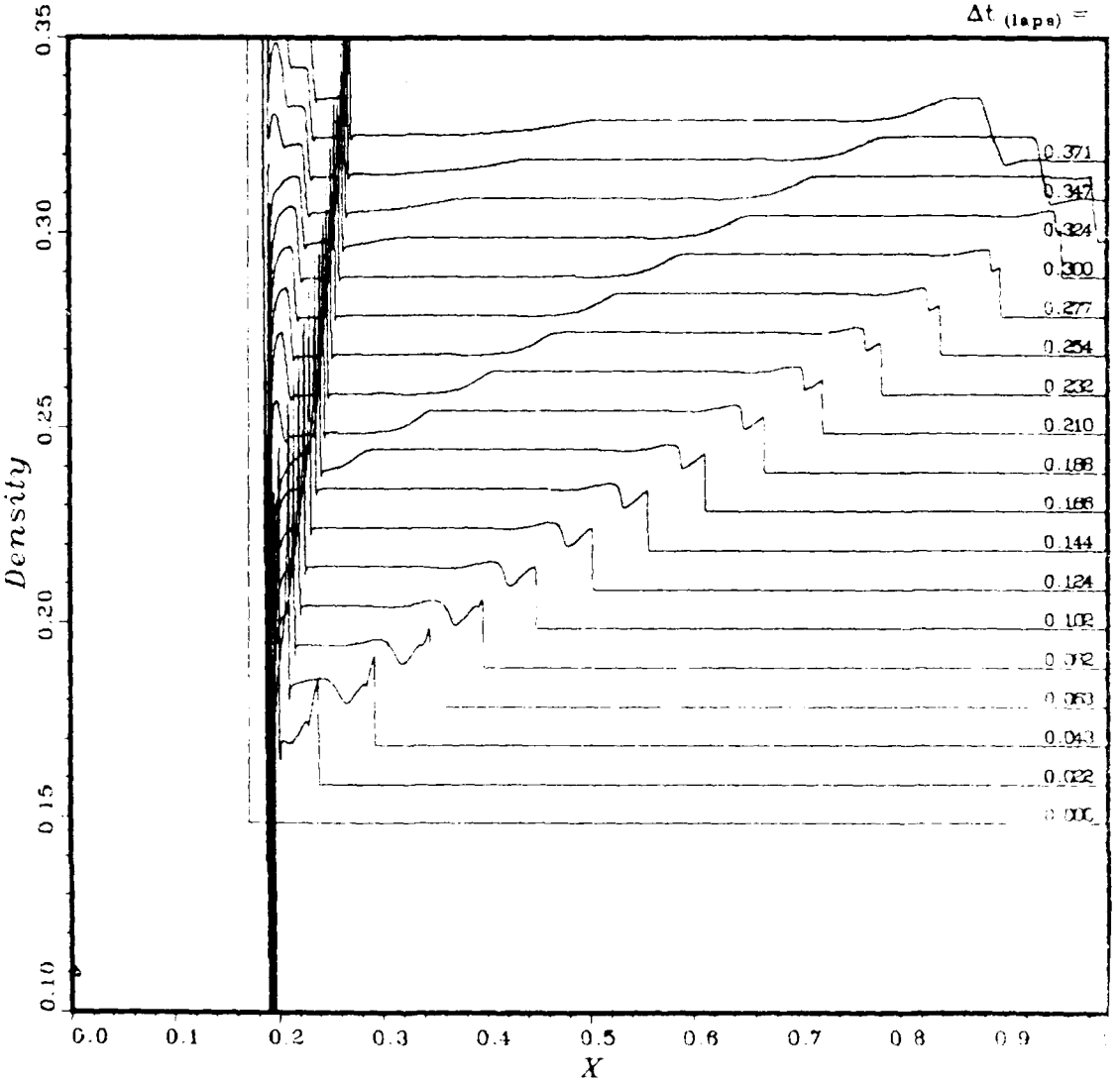


Figure 33. Magnified density versus distance, case 8, zero opening time

velocity

CASE~ 8q: BRL8 – PLOT 1
Offset, Δy = 3.000

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_i$ = 0.911

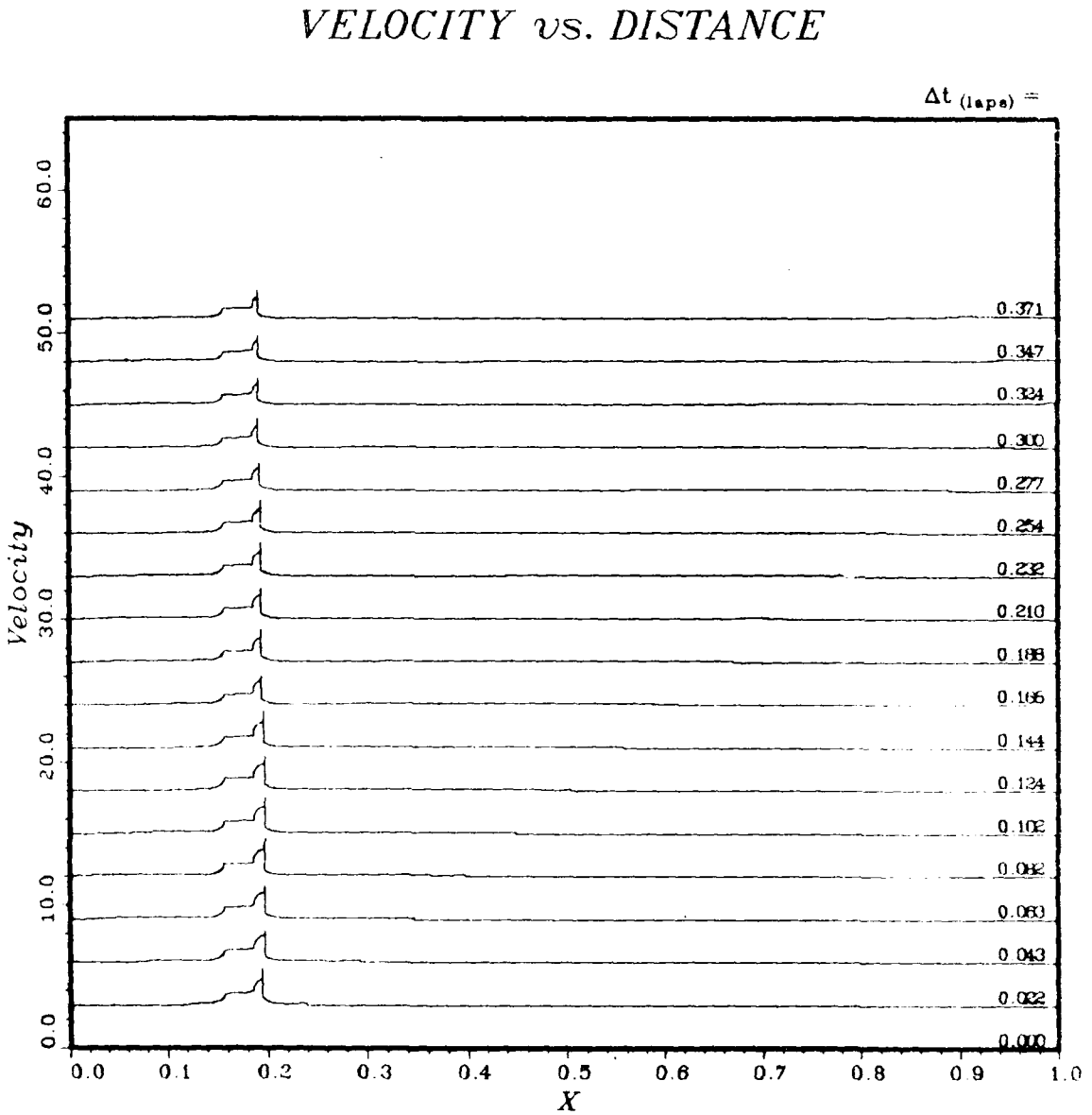
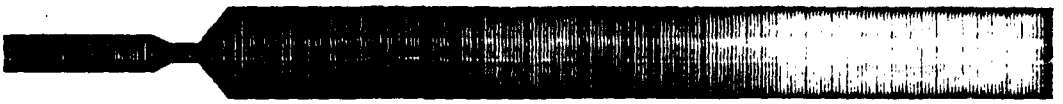


Figure 34. Velocity versus distance, case 8, zero opening time

velocity

CASE~ 8q: BRL8 - PLOT
Offset, Δy = 0.3

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_1$ = 0.911



VELOCITY vs. DISTANCE

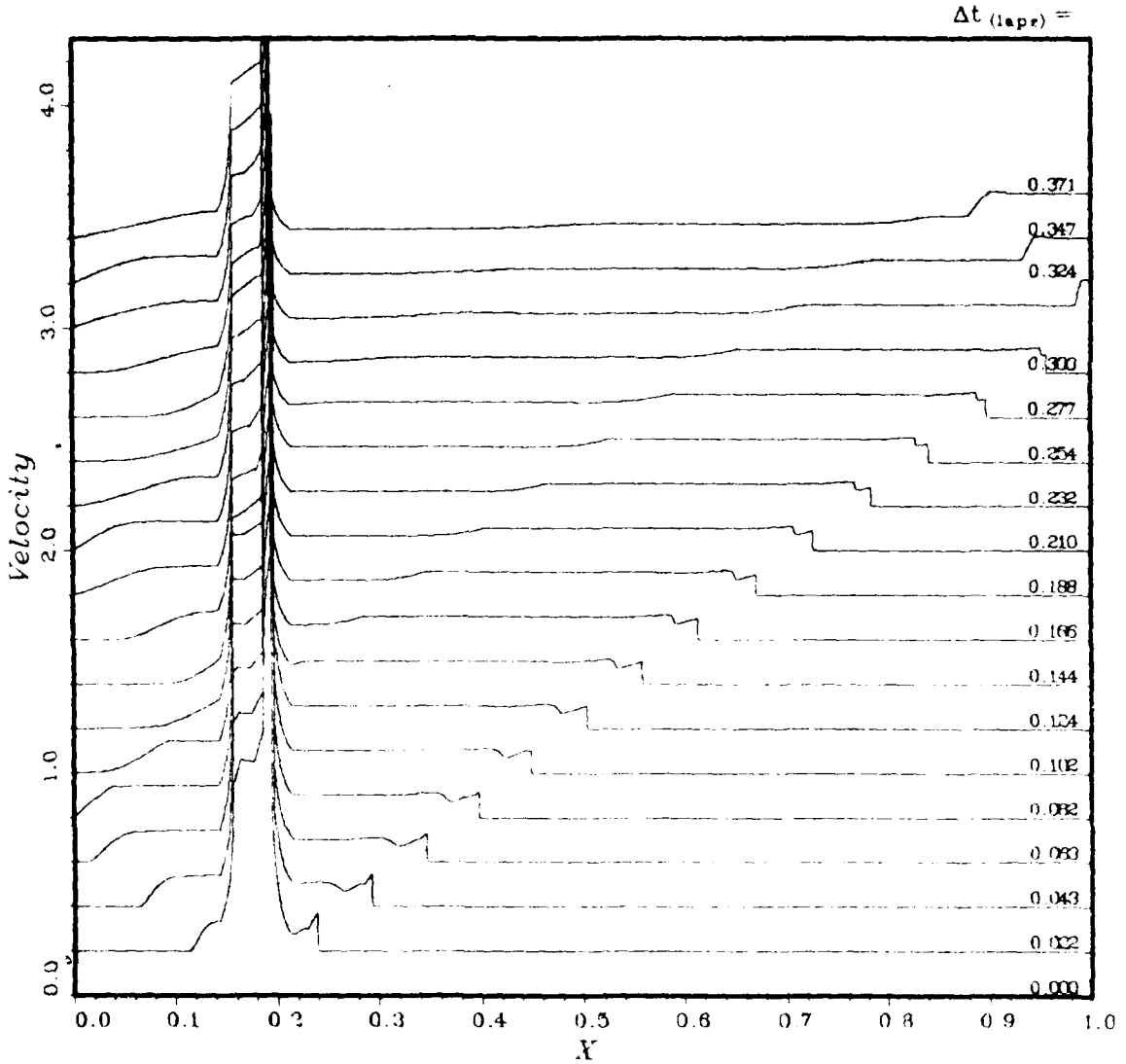


Figure 35. Magnified velocity versus distance, case 8, zero opening time

PLOT 5 03.06.46 FRI 8 JAN, 1988 JOB#1057595, ISSCO DISSPLA 10.0

sound speed

CASE~ 8q: BRL8 -- PLOT 1
Offset, Δy = 1.500

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000; T_{41} = 1.040
$XSTA_i$ = 0.911

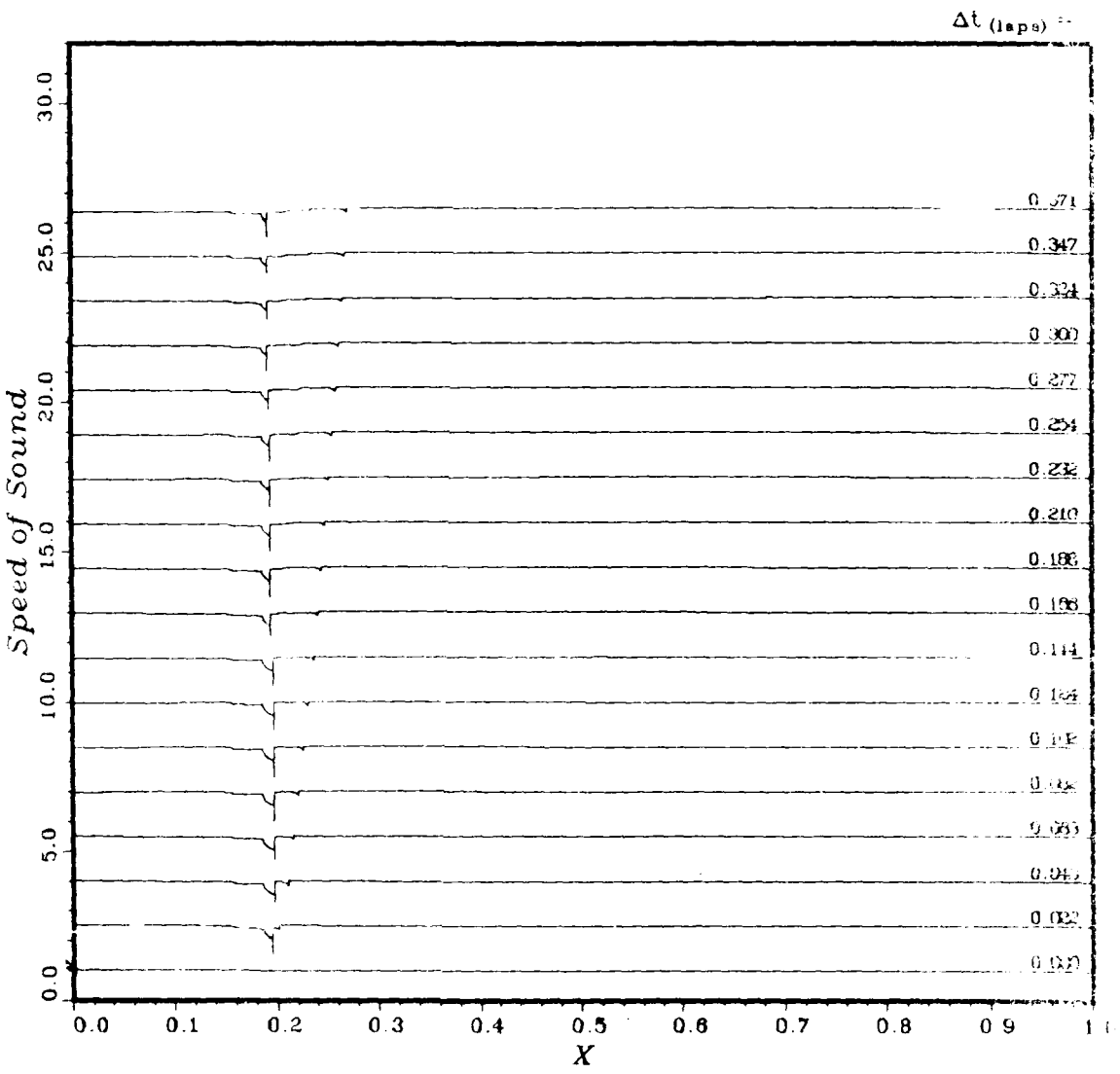


Figure 36. Sound speed versus distance, case 8, zero opening time

sound speed

CASE~ 8q: BRL8 - PLOT 1
Offset, Δy = 0.000

L_{ref} = 140.0 m
V_{drv} = 512.9 m^3
P_{41} = 7.000: T_{41} = 1.040
$XSTA_1$ = 0.911

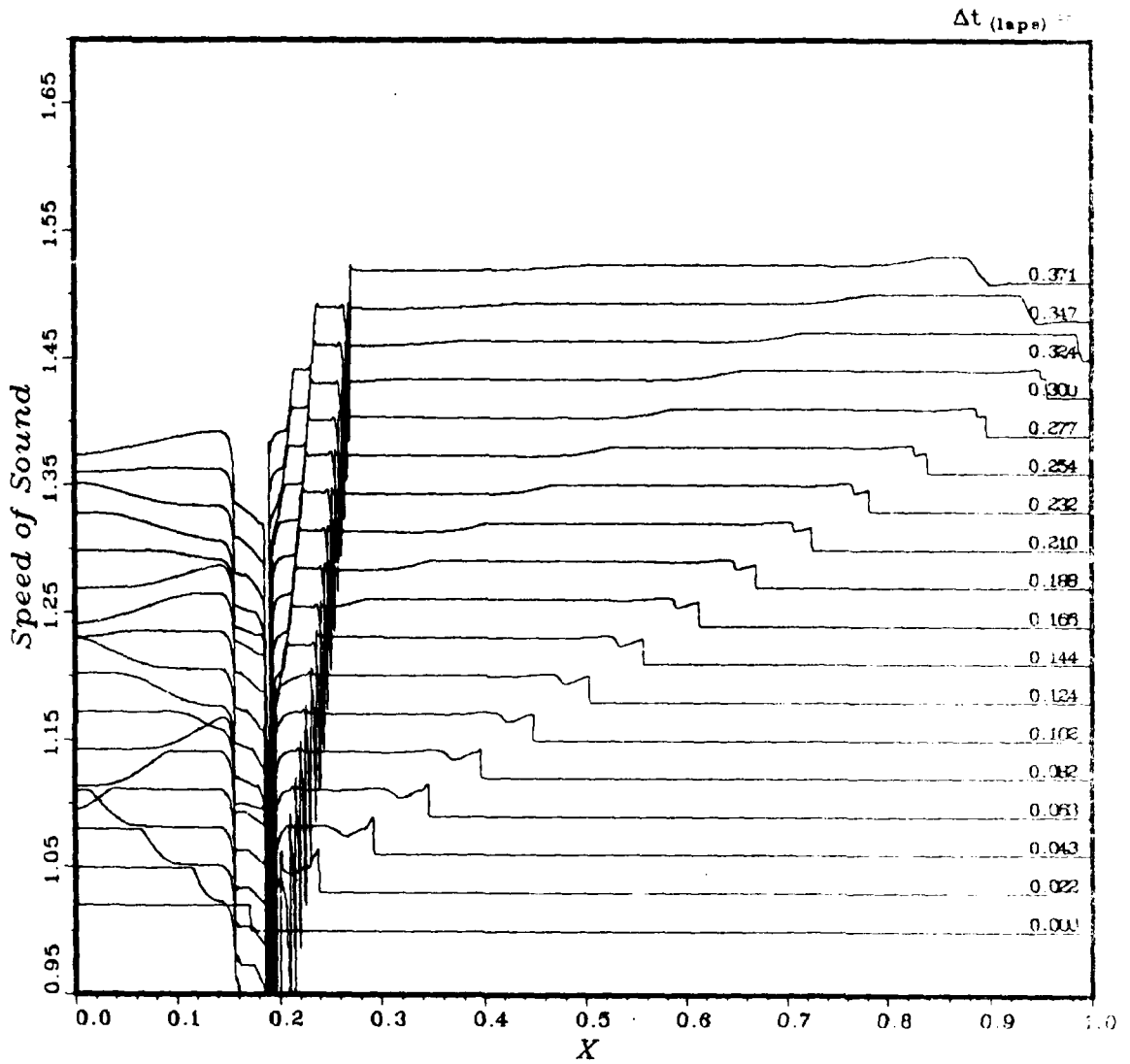


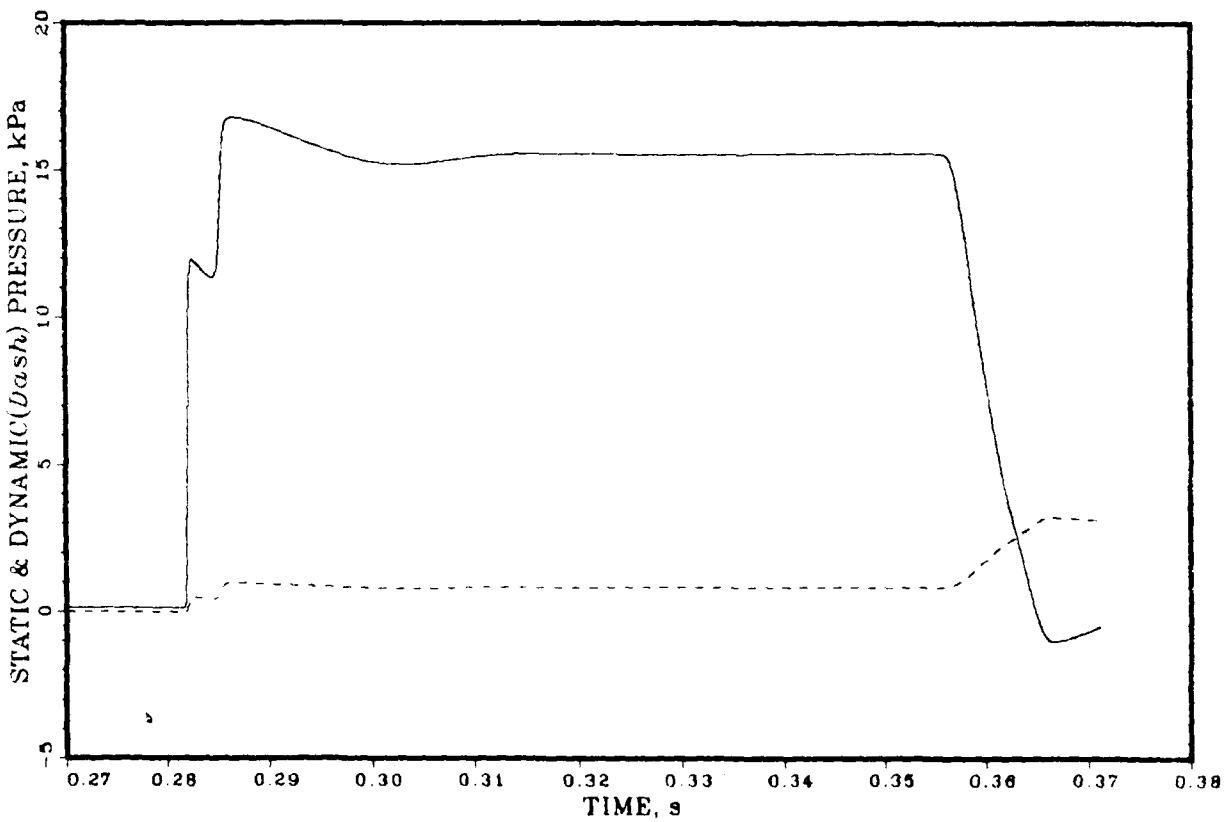
Figure 37. Magnified sound speed versus distance, case 8, zero opening time

PLOT 7 03.08.19 FRI 8 JAN, 1988 JOB-P1057385, ISSCO DISSPLA 10.0

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8q: BRL8			P-so	= 11.96 kPa	(1.735 psi)
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 282.1 ms		
L-drv	= 20.00 m	P-drv	= 7.000 atm	PPD	= 0.083 s	(0.245 s)
V-drv	= 512.9 m^3	P-amb	= 101.3 kPa	I-so	= 1.209 kPa-s	(0.169 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.496 kPa	
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.078 kPa-s	(1.778 kT)

PRESSURE-TIME HISTORY



PLOT 1 08.22.79 FRI 8 JAN, 1988 JOB-F1061701, ISSCO DISSPLA 10.0

Figure 38. Pressure versus time, case 8, zero opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE: = 8q: BRL8			P-so	= 11.98 kPa	(1.735 psi)
L-ref = 140.0 m	X-sta = 97.50 m		t-a	= 282.1 ms	
L-drv = 20.00 m	P-drv = 7.000 atm		PPD	= 0.063 s	(0.245 s)
V-drv = 512.9 m^3	P-amb = 101.3 kPa		I-so	= 1.209 kPa-s	(0.169 kT)
L-dvn = 110.0 m	T-amb = 288.2 K		Q-s	= 0.496 kPa	
L-rwe = 0.000 m	T4/T1 = 1.040		I-dyn	= 0.078 kPa-s	(1.778 kT)

PRESSURE-TIME HISTORY

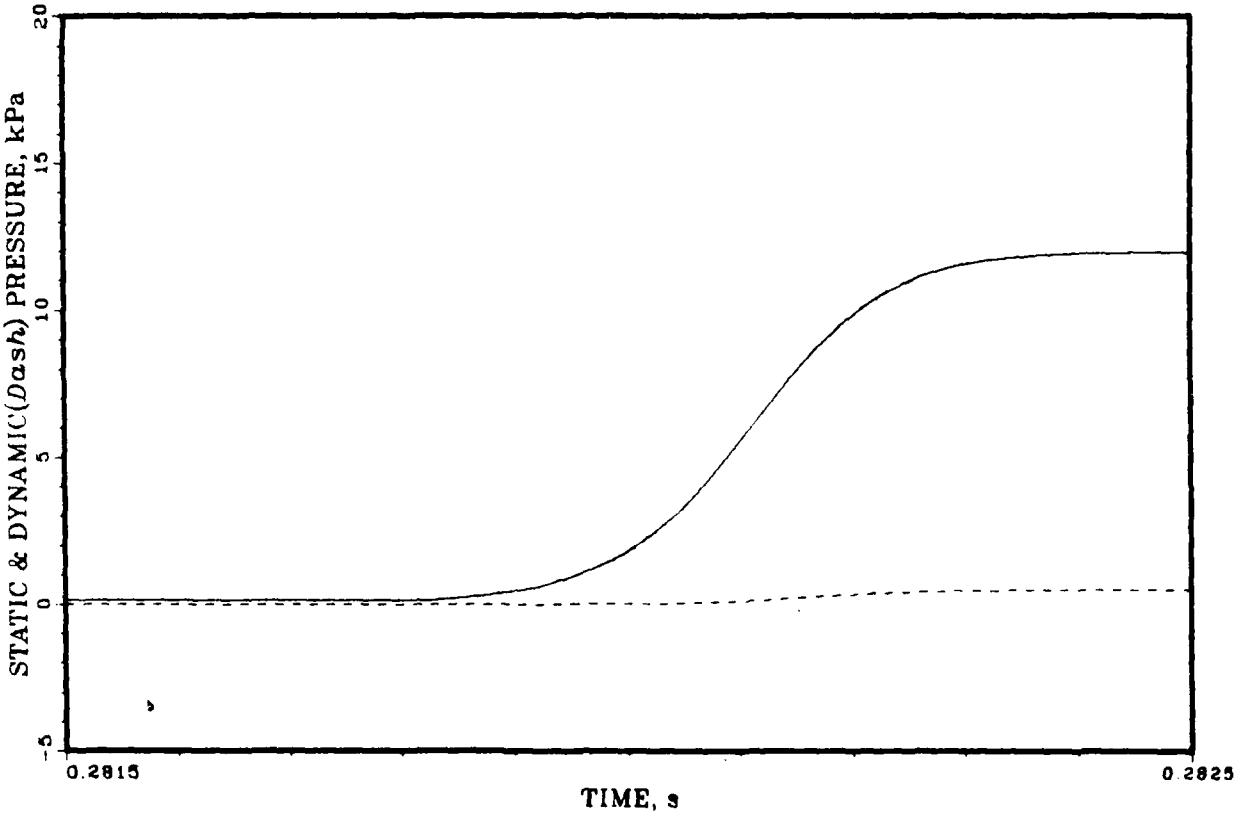


Figure 39. Detail, pressure versus time, case 8, zero opening time

PLOT 1 08.32.24 FRI 8 JAN, 1988 JOB-P1061968, ISSCO DISSPLA 10.0

pressure

CASE~ 8h: BRL8 – PLOT 1
Offset, Δy = 1.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

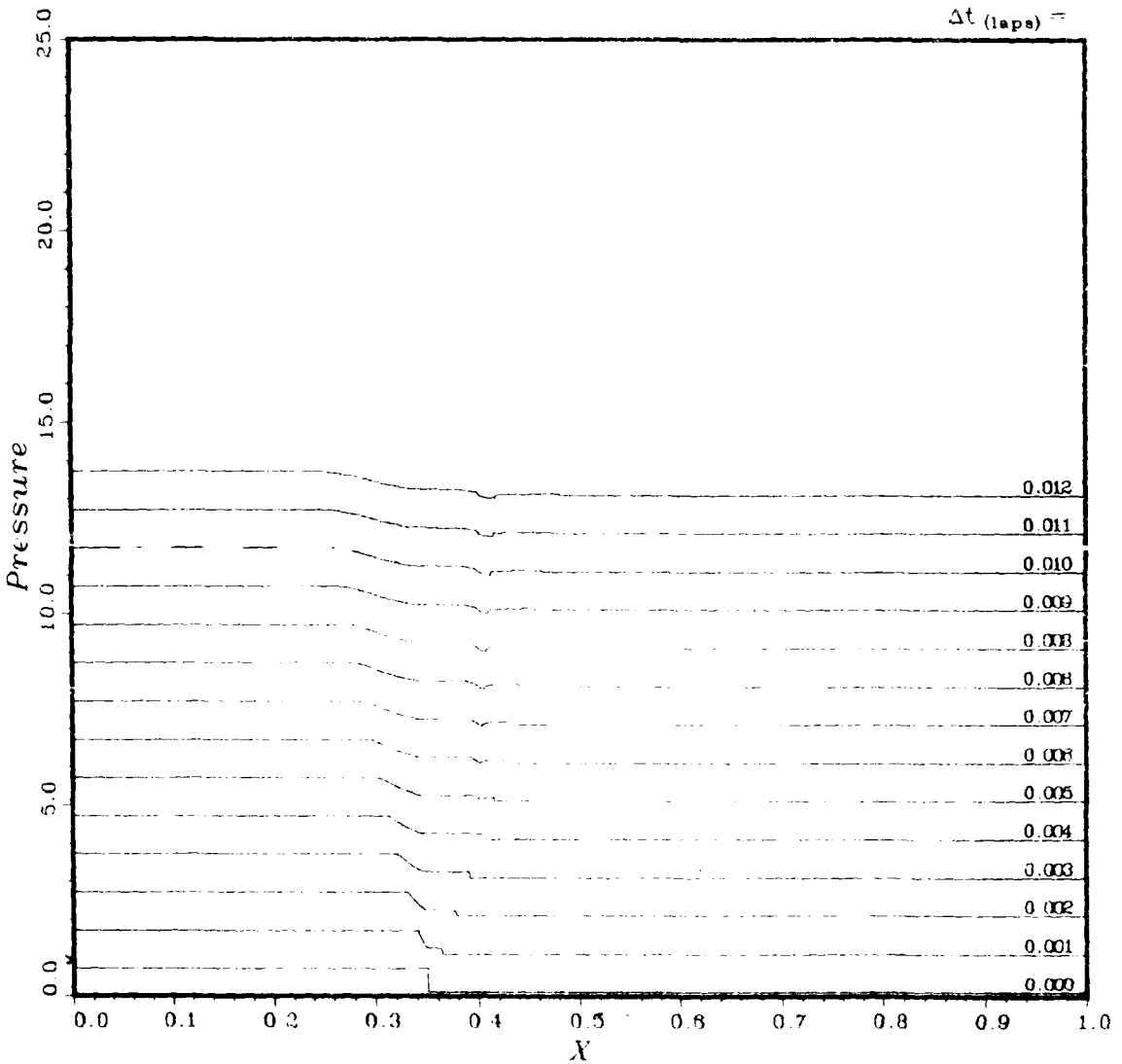


Figure 40. Detail study, pressure versus distance, part 1

pressure

CASE~ 8h: BRL8 - PLOT 2
Offset, Δy = 1.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

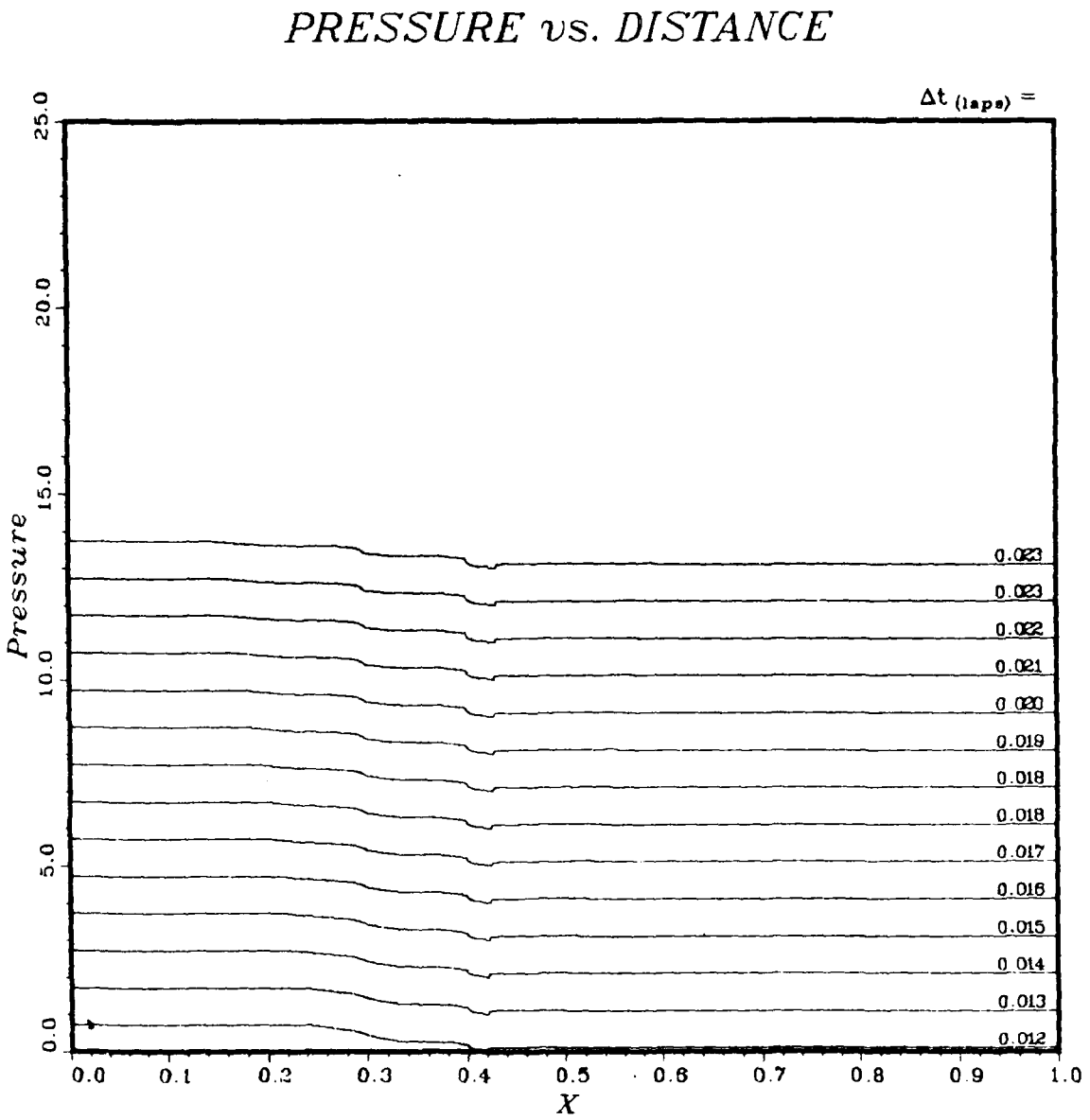


Figure 41. Detail study, pressure versus distance, part 2

LOT 5 18.45.26 FRI 18 DEC, 1987 JOB=P1053500, [5500 DISPLA 16.0

pressure

CASE~ 8h: BRL8 - PLOT 3
Offset, Δy = 1.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_j$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

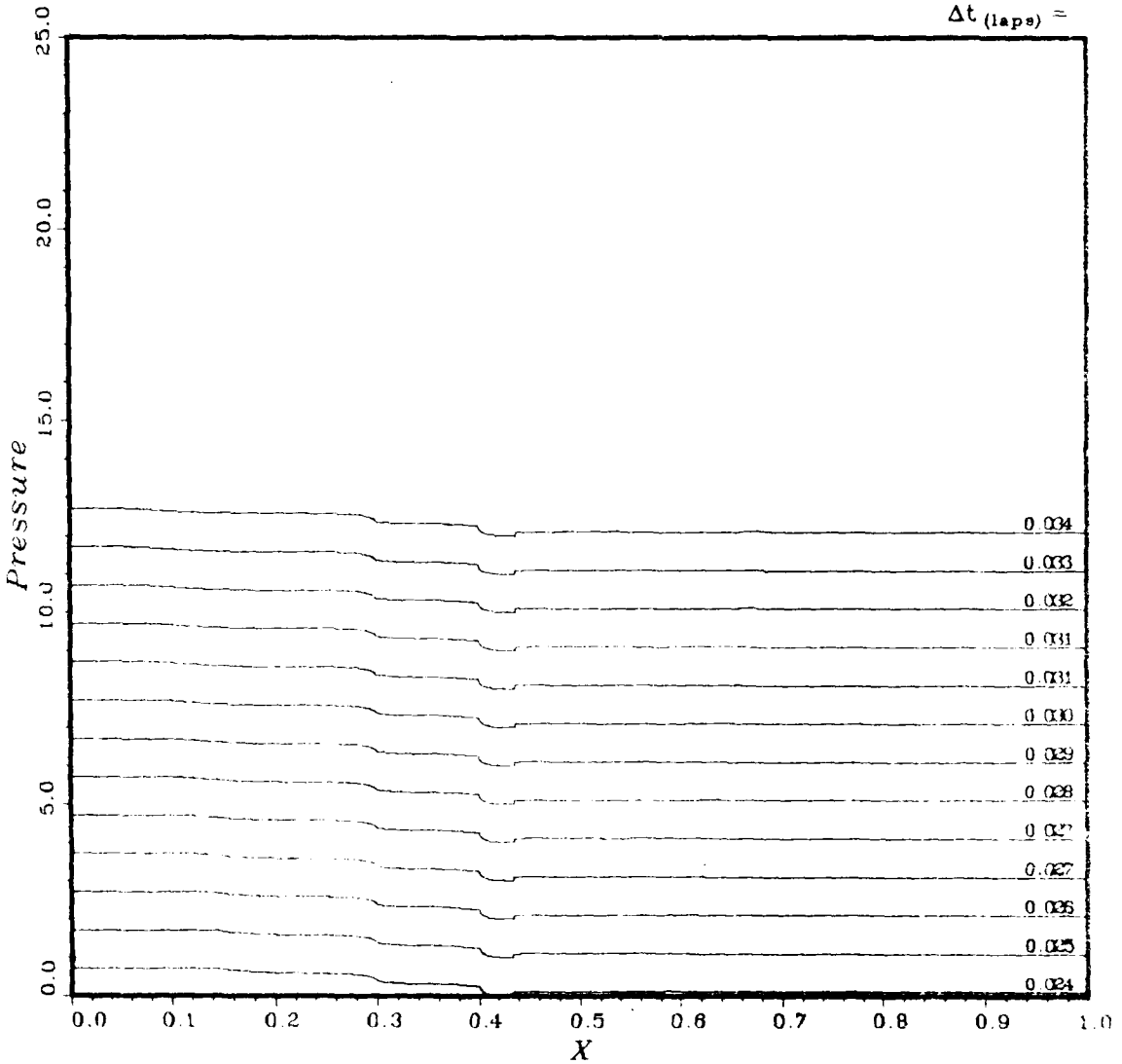


Figure 42. Detail study, pressure versus distance, part 3

pressure

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 278.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

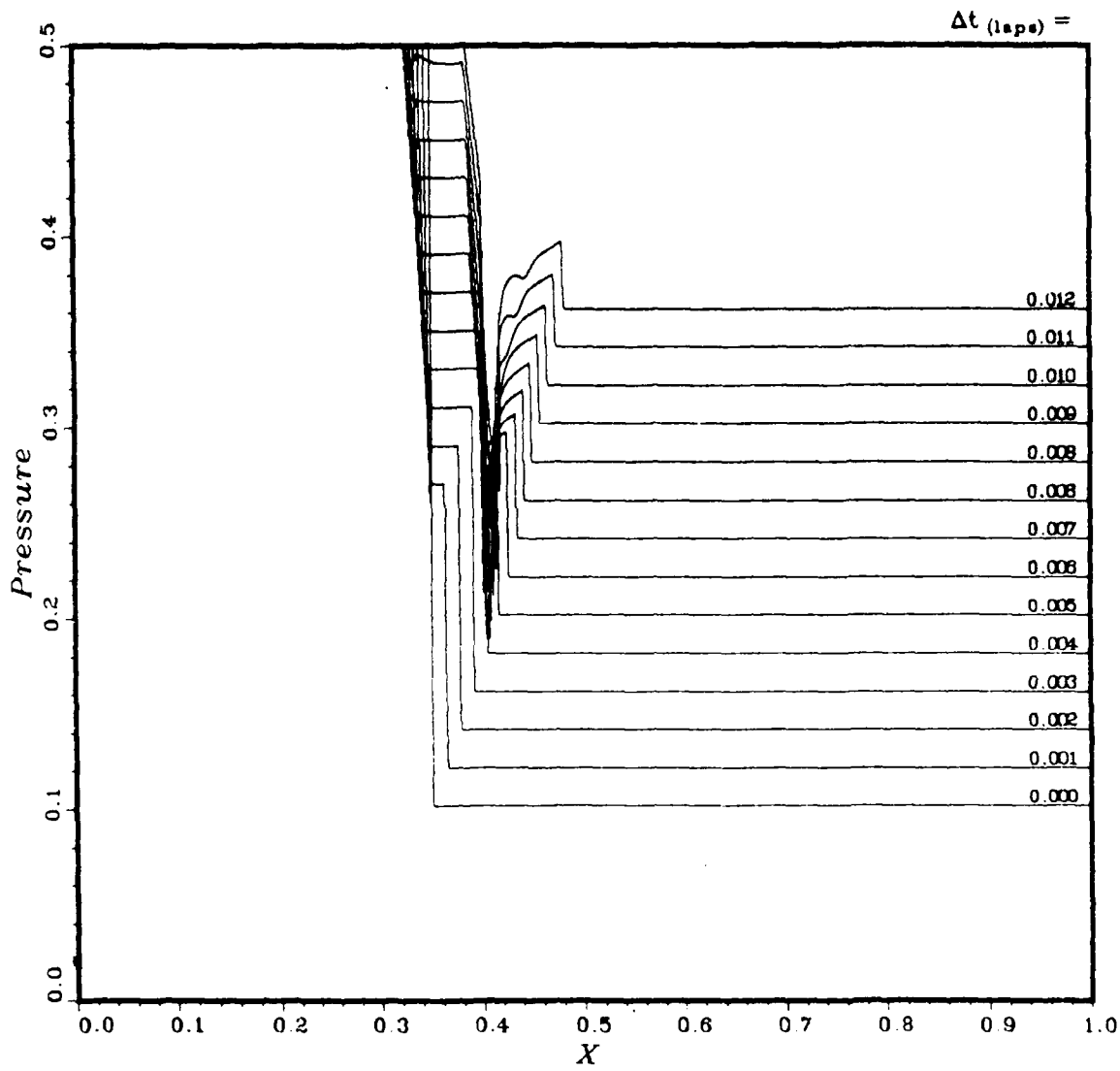


Figure 43. Detail study, magnified pressure versus distance, part 1

18.44.30 FRI 18 DEC, 1987 JOB-P:D53500, ISSCO DISPLA 10.0

pressure

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

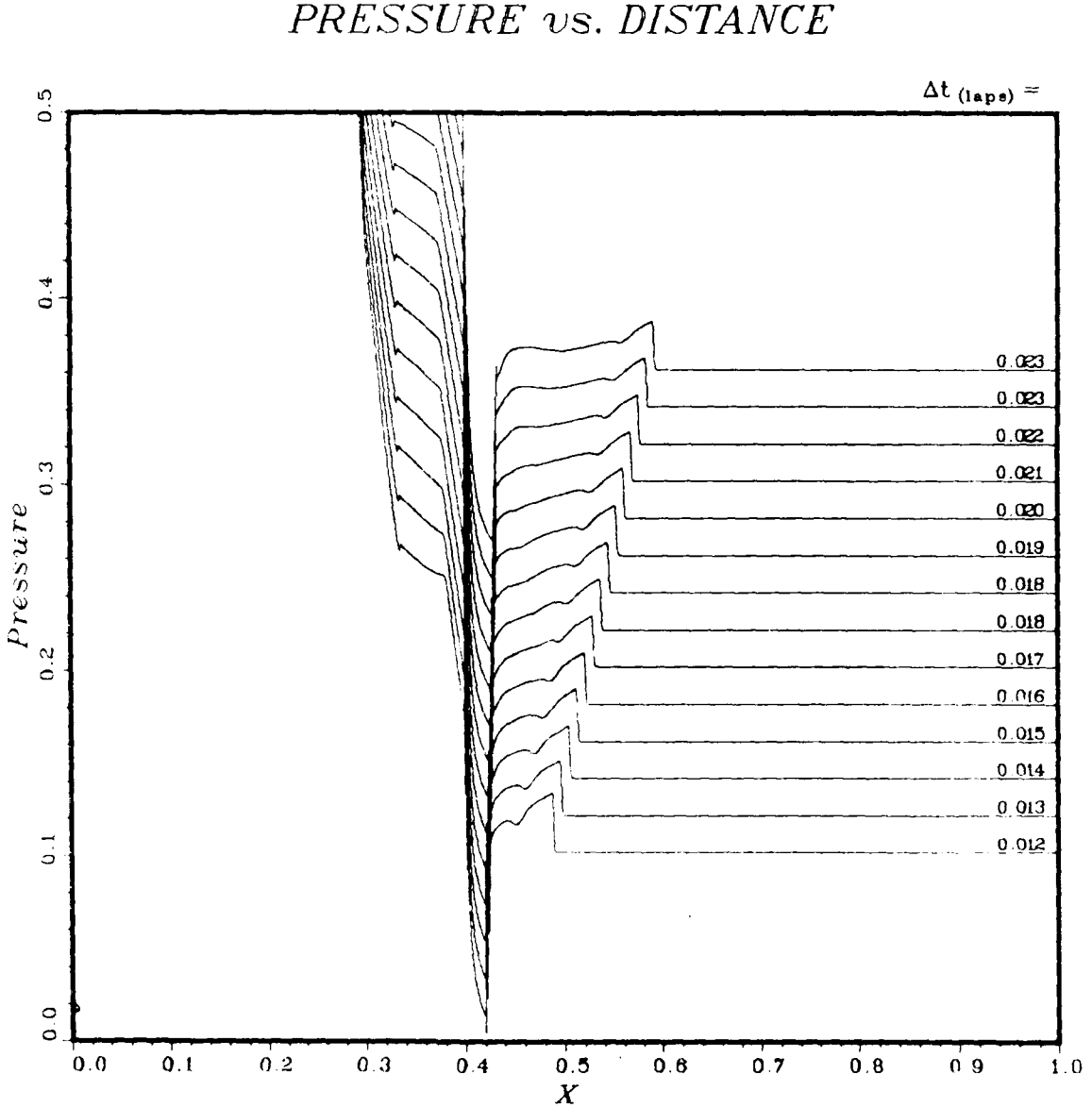


Figure 44. Detail study, magnified pressure versus distance, part 2

pressure

CASE~ 8h: BRL8 – PLOT 3
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

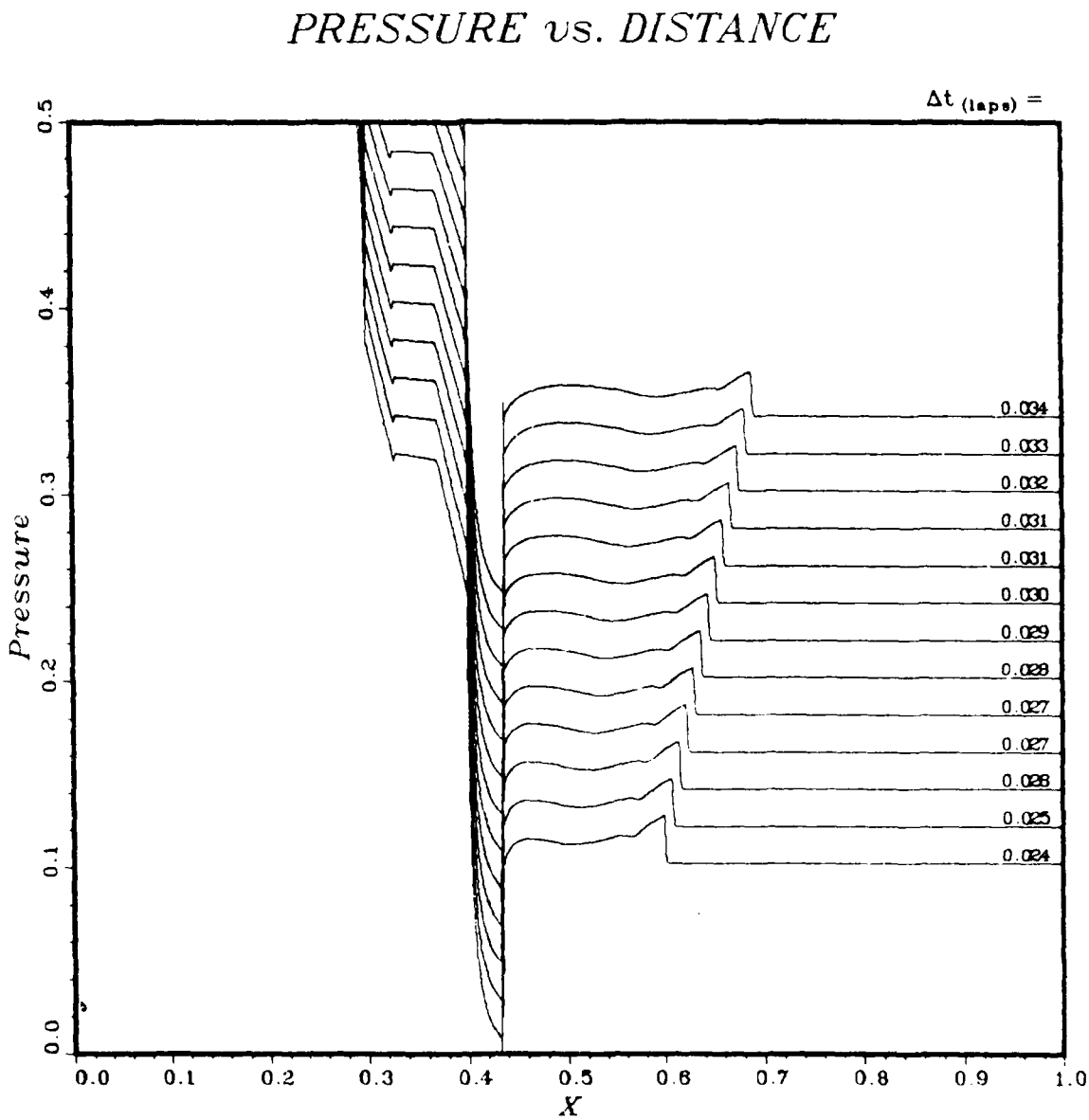


Figure 45. Detail study, magnified pressure versus distance, part 3

PLOT 4 18.44.55 FRI 18 DEC, 1987 JOB=P1053500, ISSCO DISSPLA 10.0

density

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.100

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

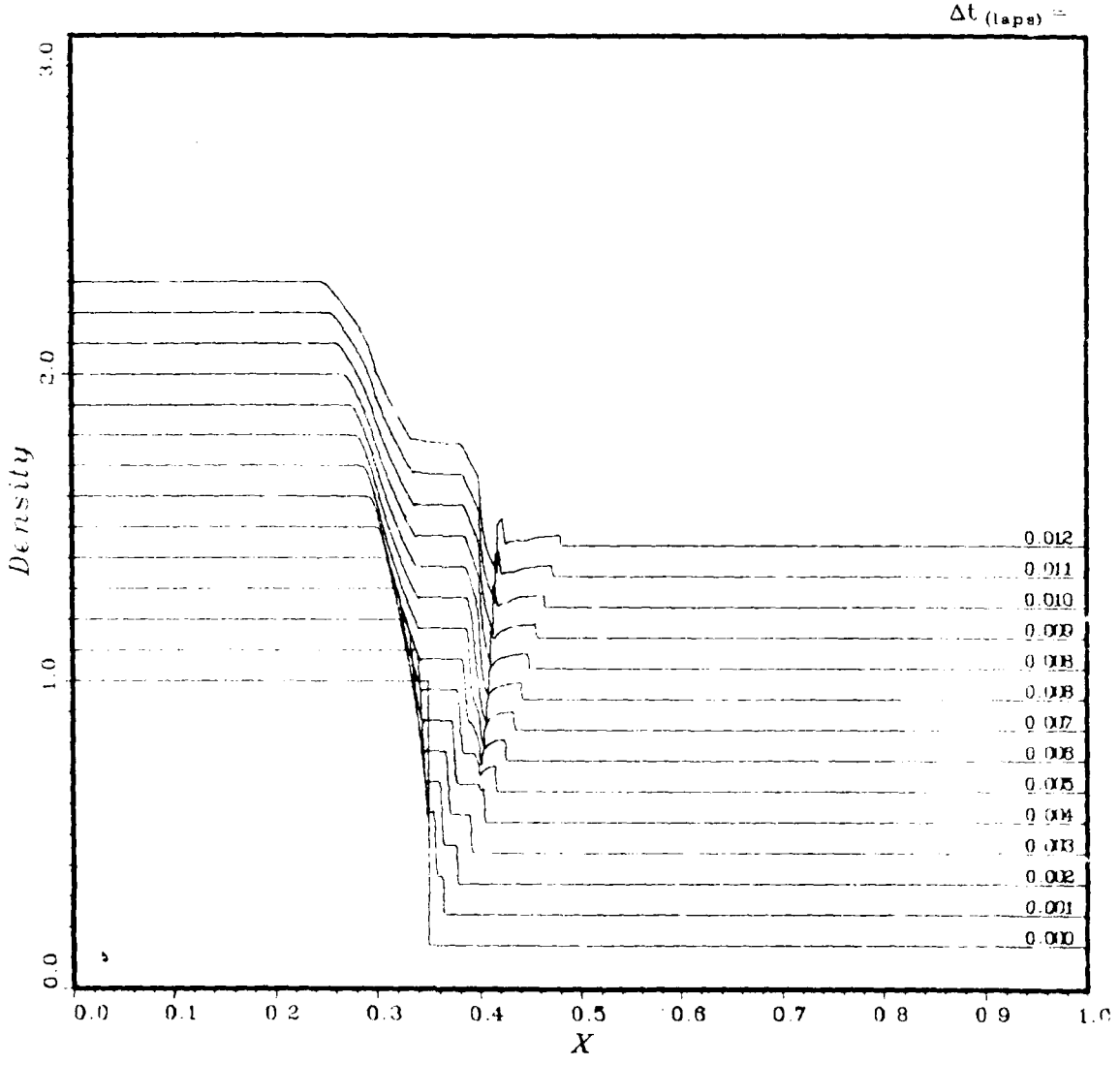


Figure 46. Detail study, density versus distance, part 1

density

CASE~ 8h: BRL8 - PLOT 2
Offset, $\Delta y = 0.100$

$L_{ref} = 40.00\ m$
$V_{drv} = 276.1\ m^3$
$P_{41} = 7.000$; $T_{41} = 1.000$
$XSTA_i = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700$

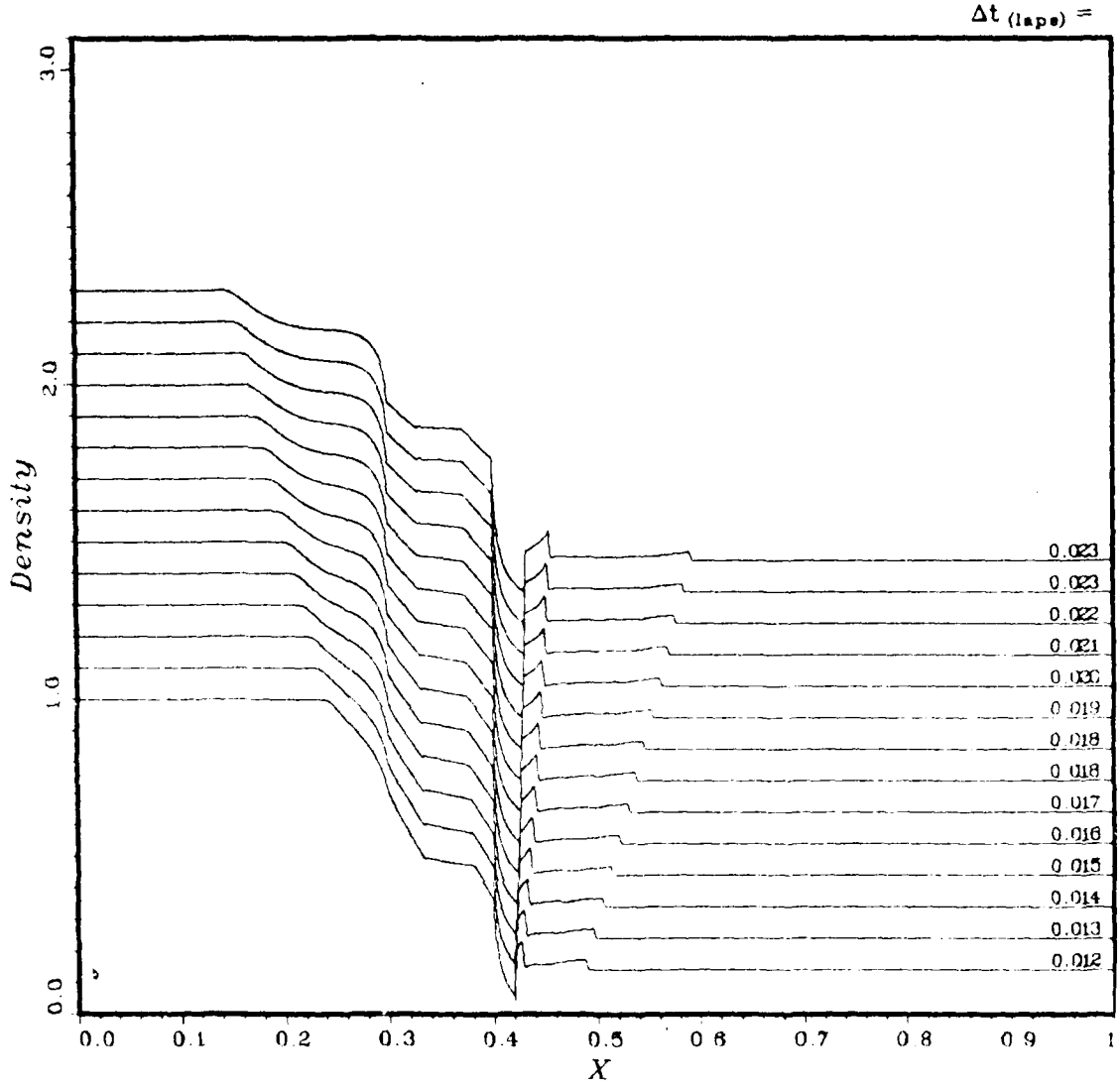


Figure 47. Detail study, density versus distance, part 2

density

CASE~ 8h: BRL8 -- PLOT 3
Offset, Δy = 0.100

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

DENSITY vs. DISTANCE

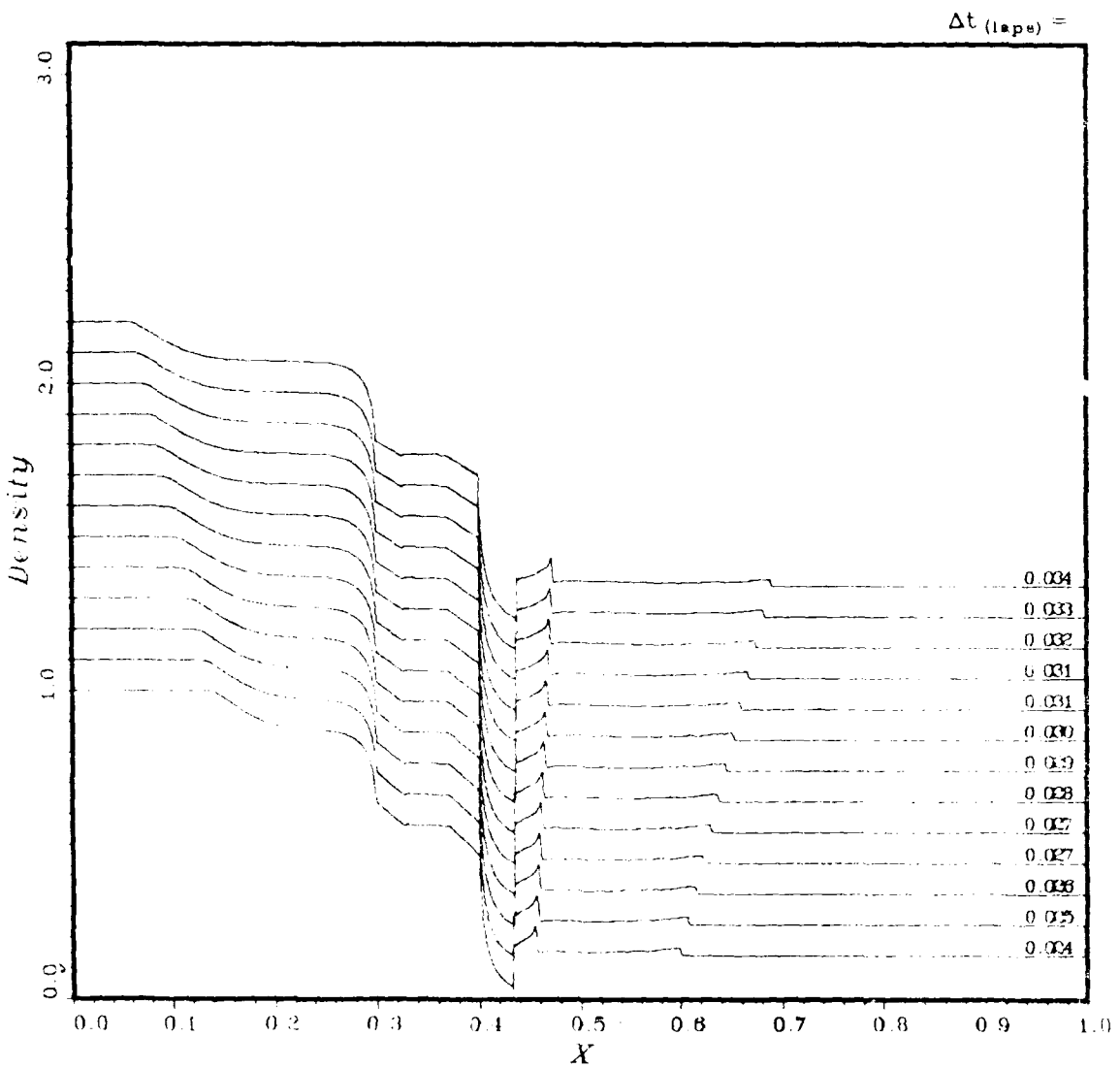


Figure 48. Detail study, density versus distance, part 3

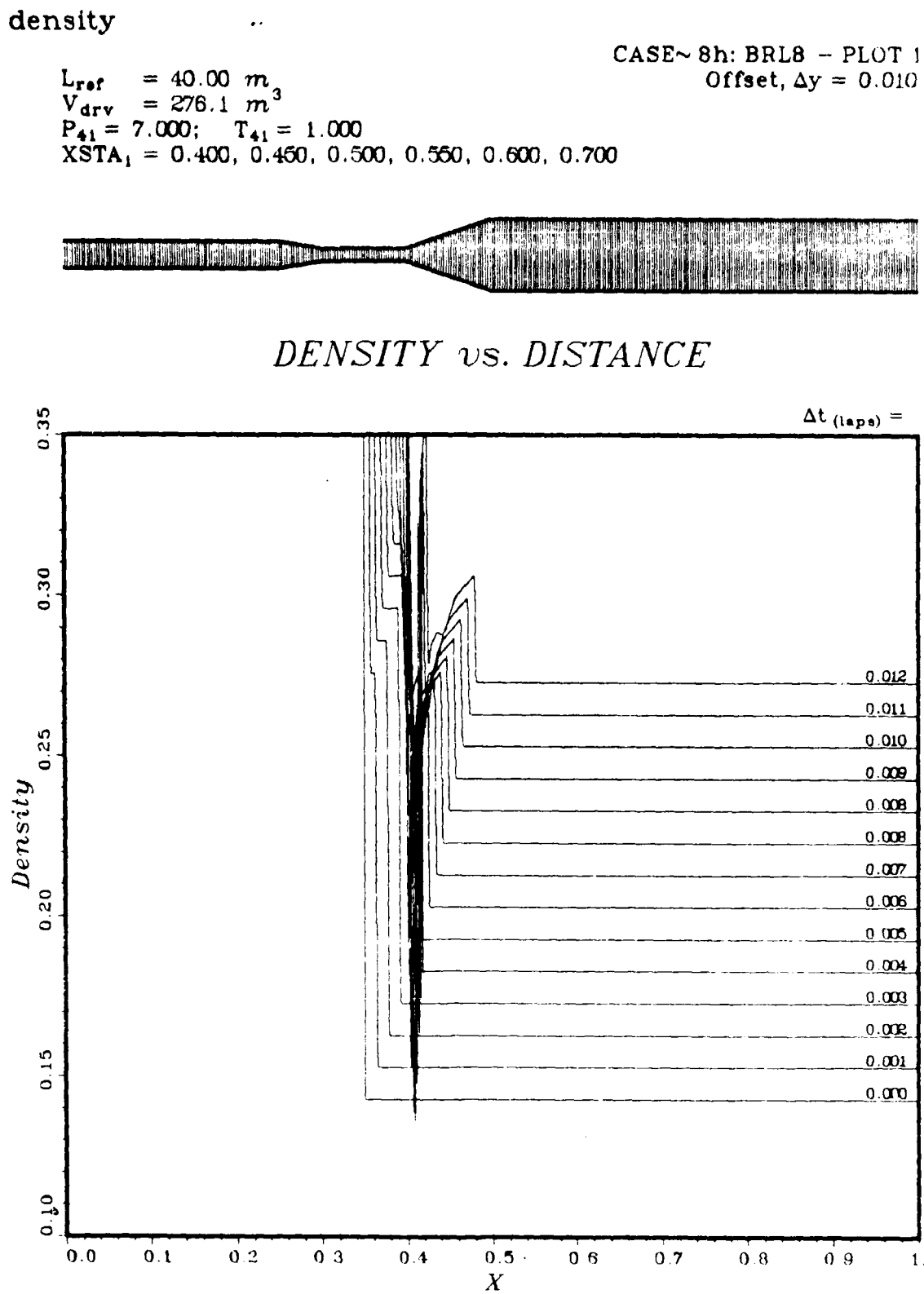


Figure 49. Detail study, magnified density versus distance, part 1

OCT 7 18.45.53 FRI 18 DEC, 1987 JOB-PID53500, ISSCO DISSPLA 10.0

density

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 0.010

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_1$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

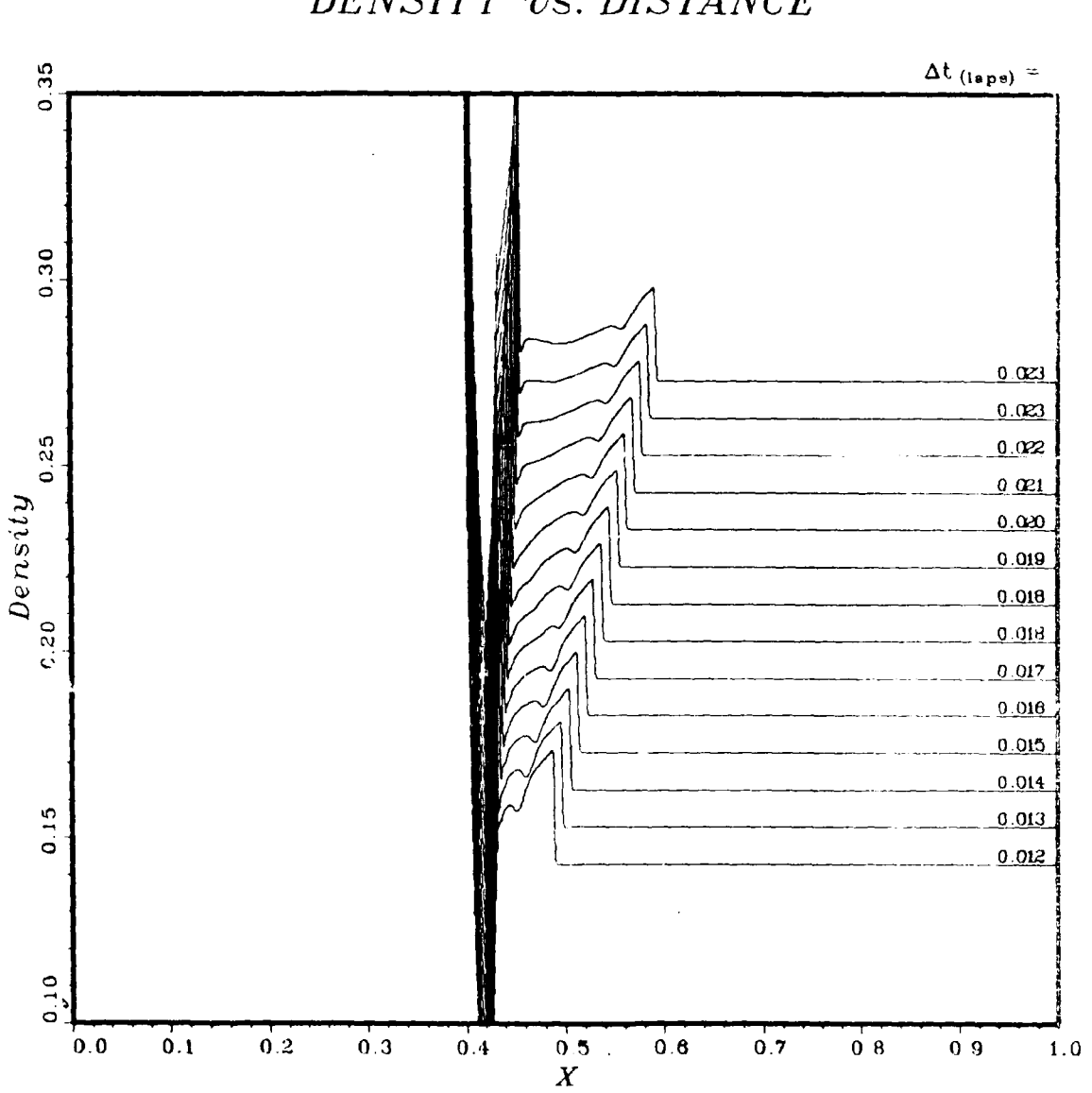


Figure 50. Detail study, magnified density versus distance, part 2

density

CASE~ 8h: BRL8 – PLOT 3
Offset, Δy = 0.010

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

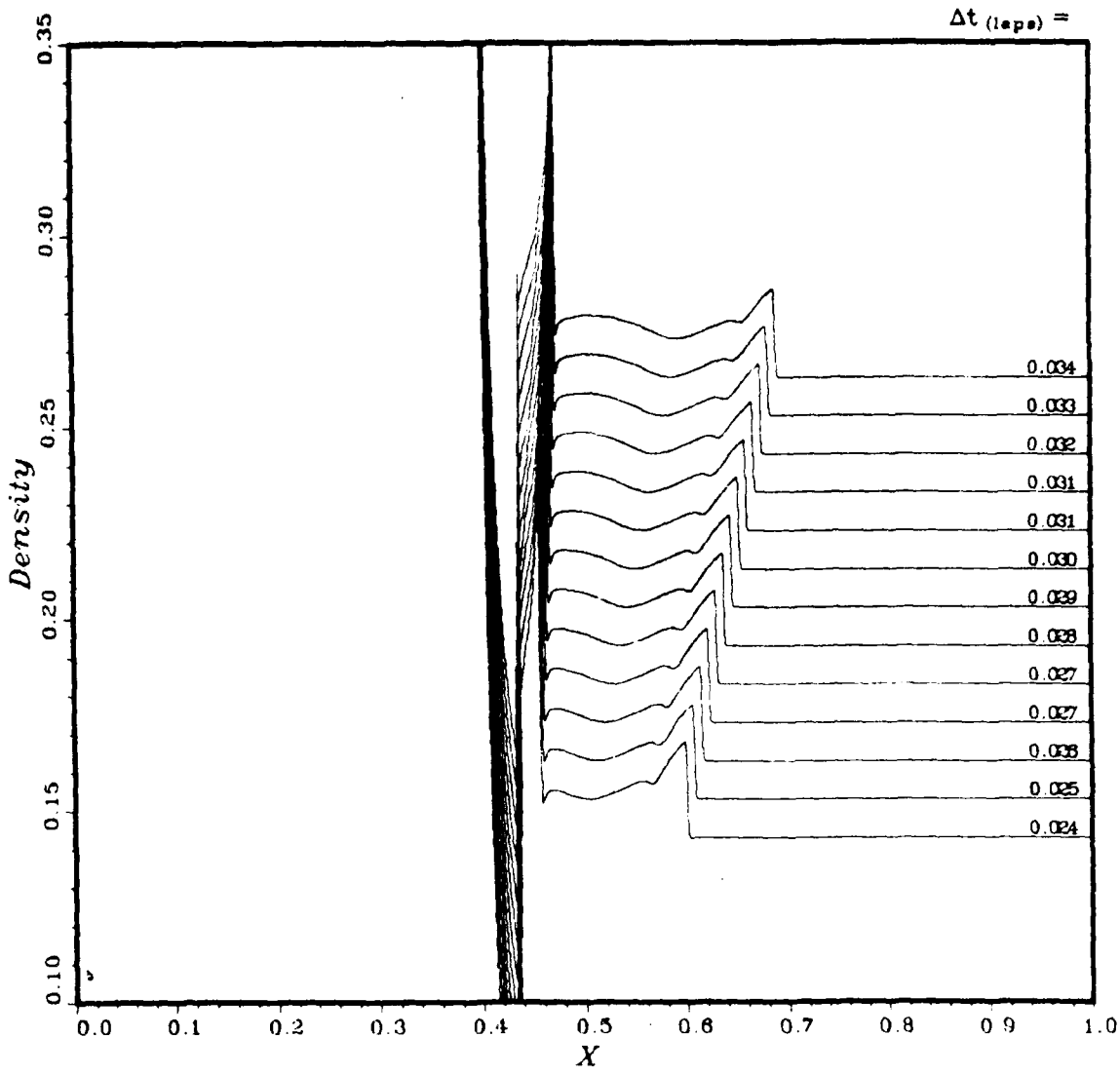


Figure 51. Detail study, magnified density versus distance, part 3

PLOT 10 18.46.17 FRI 18 DEC, 1987 JOB-P1053500, ISSCO DISSPLA 10.0

velocity

CASE~ 8h: BRL8 – PLOT 1
Offset, Δy = 3.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

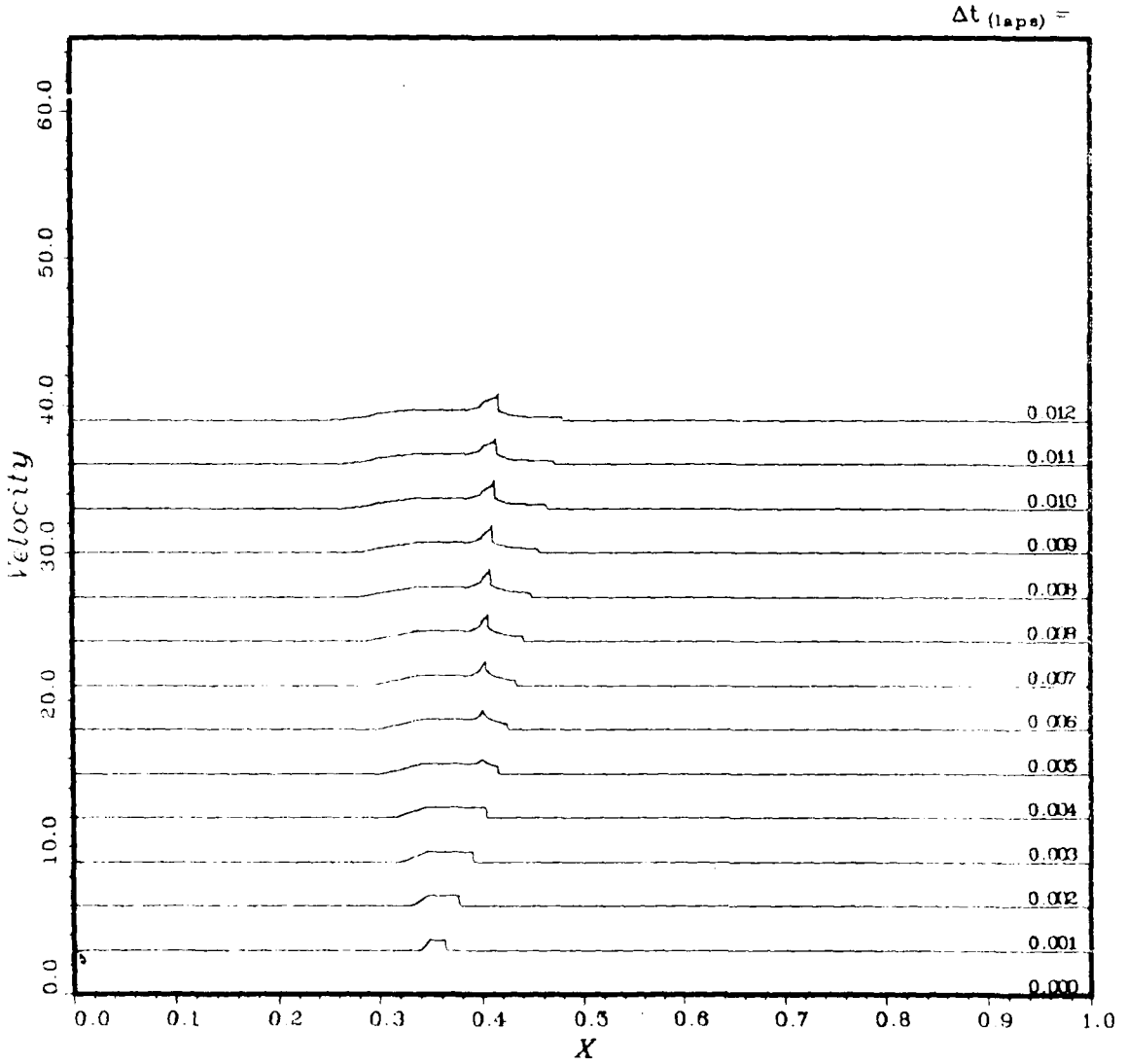


Figure 52. Detail study, velocity versus distance, part 1

velocity

CASE~ 8h: BRL8 - PLOT 2
Offset, Δy = 3.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

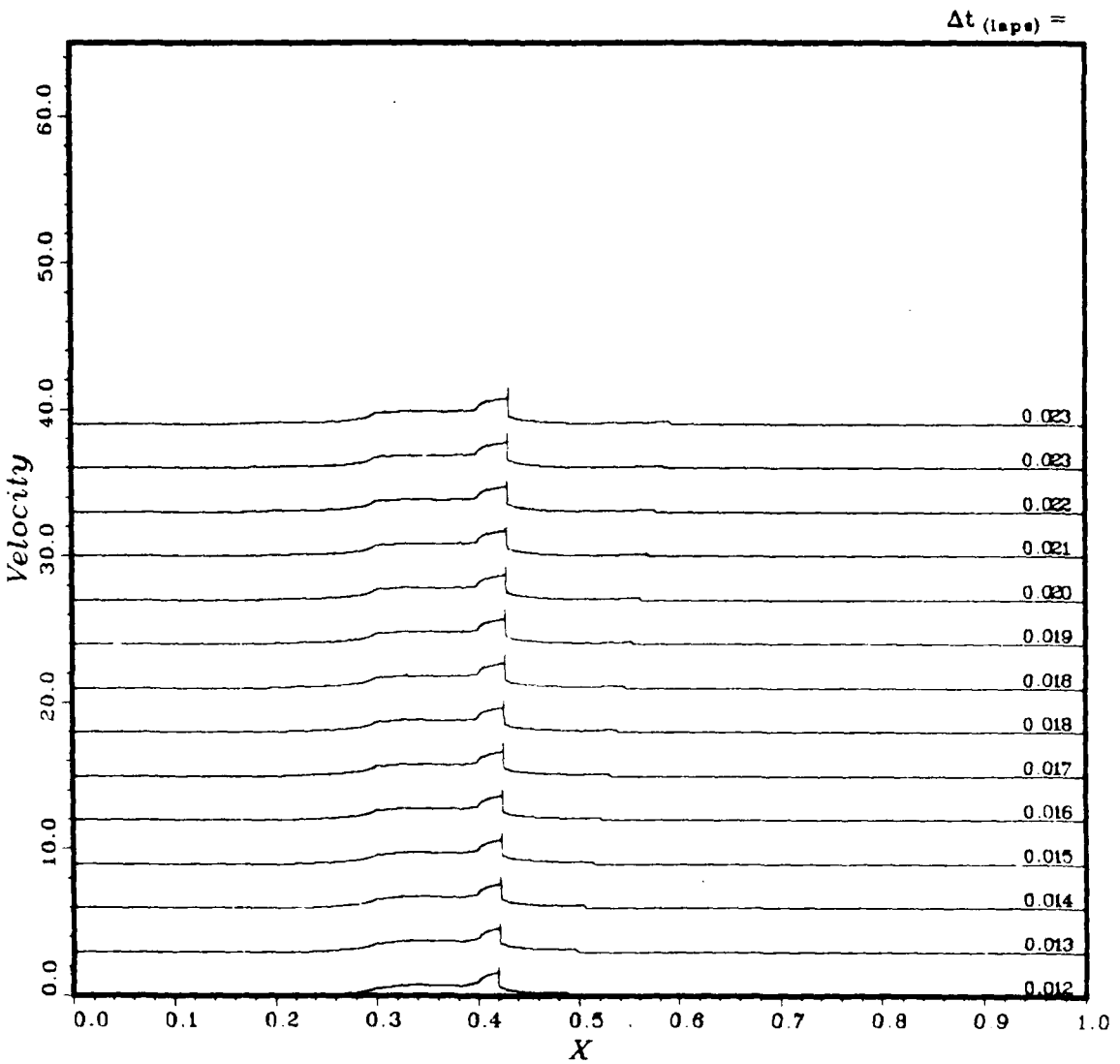


Figure 53. Detail study, velocity versus distance, part 2

LUT 17 18.48.19 FRI 18 DEC, 1987 JOB=PIDS3500, ISSCO DISSPLA 10.0

velocity

CASE~ 8h: BRL8 - PLOT 3
Offset, Δy = 3.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

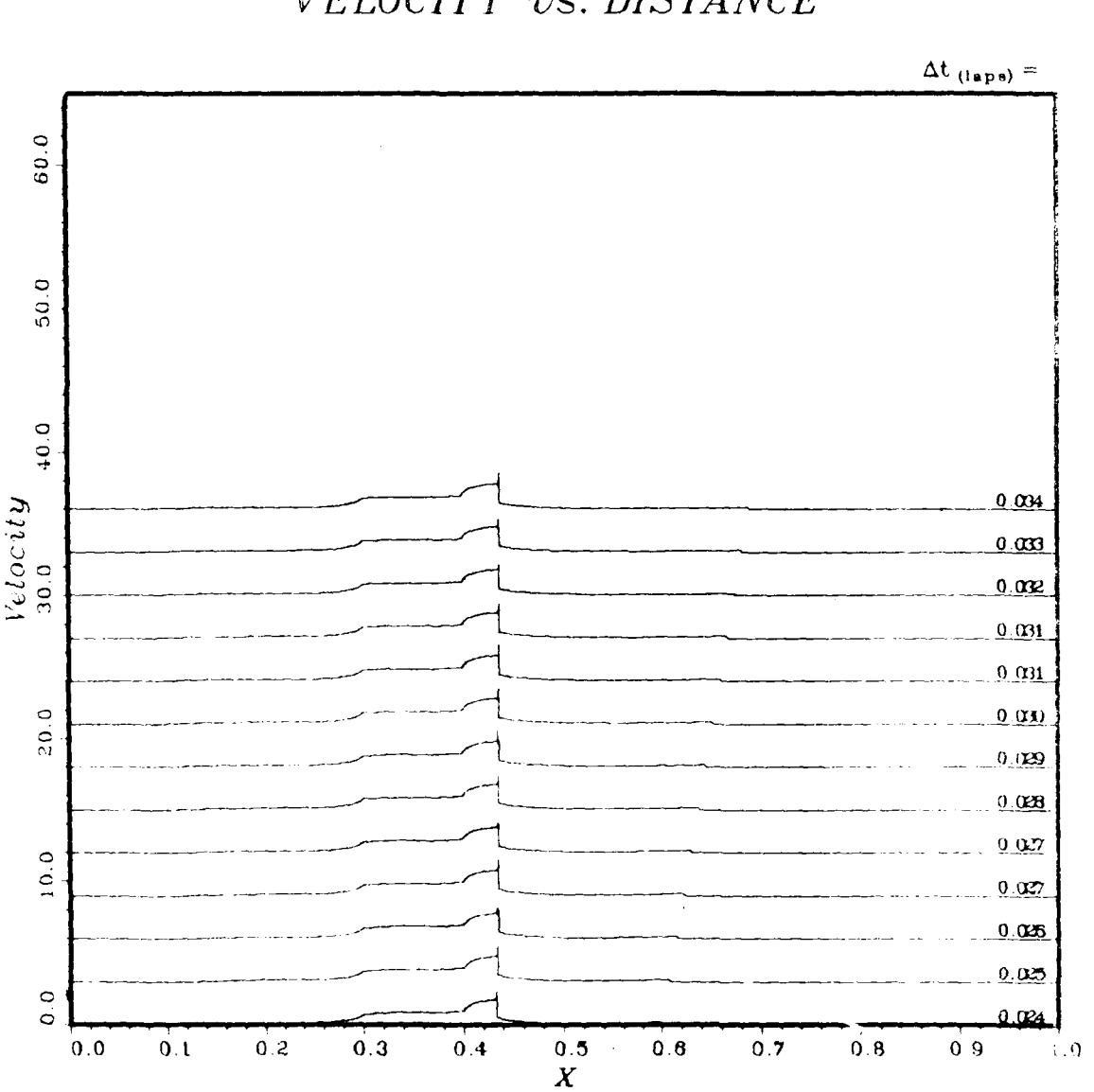
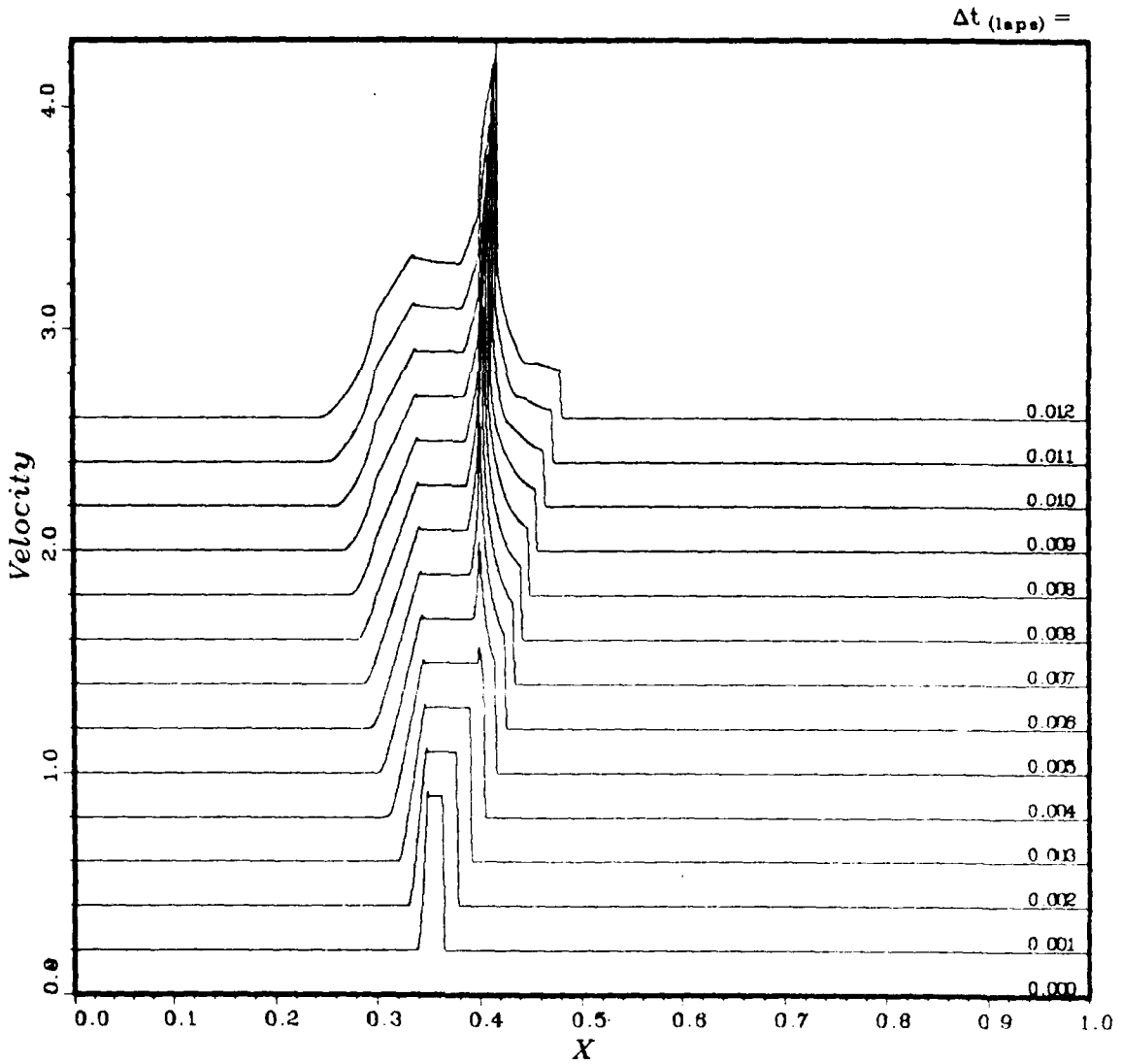


Figure 54. Detail study, velocity versus distance, part 3

velocity

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700



PLOT 13 18.47.18 FRI 18 DEC, 1987 JOB-#10053500, ISSCO DISSPLA 10.0

Figure 55. Detail study, magnified velocity versus distance, part 1

velocity

CASE~ 8h: BRL8 - PLOT 2
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

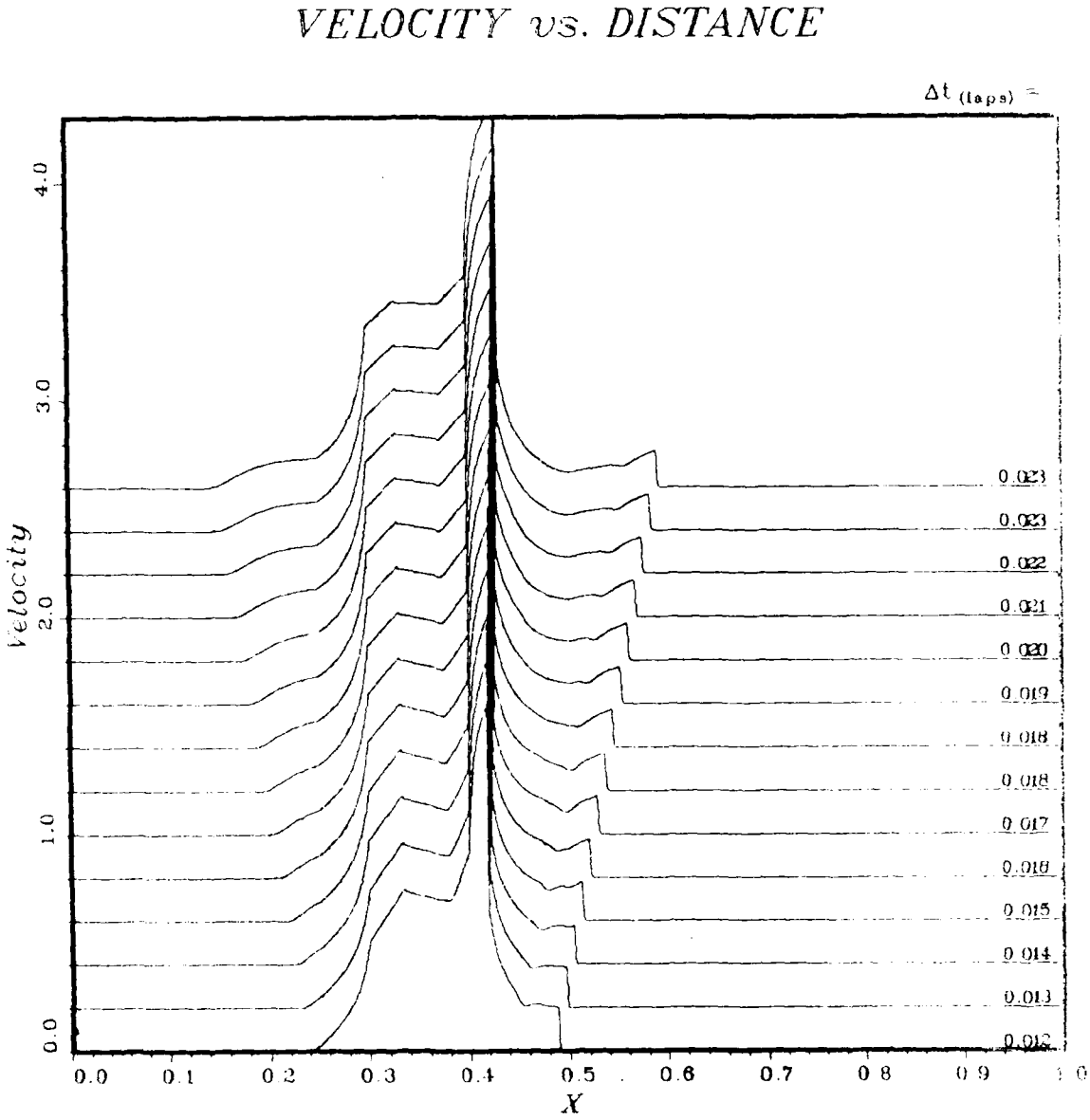


Figure 56. Detail study, magnified velocity versus distance, part 2

velocity

CASE~ 8h: BRL8 – PLOT 3
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{4i} = 7.000; T_{4i} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

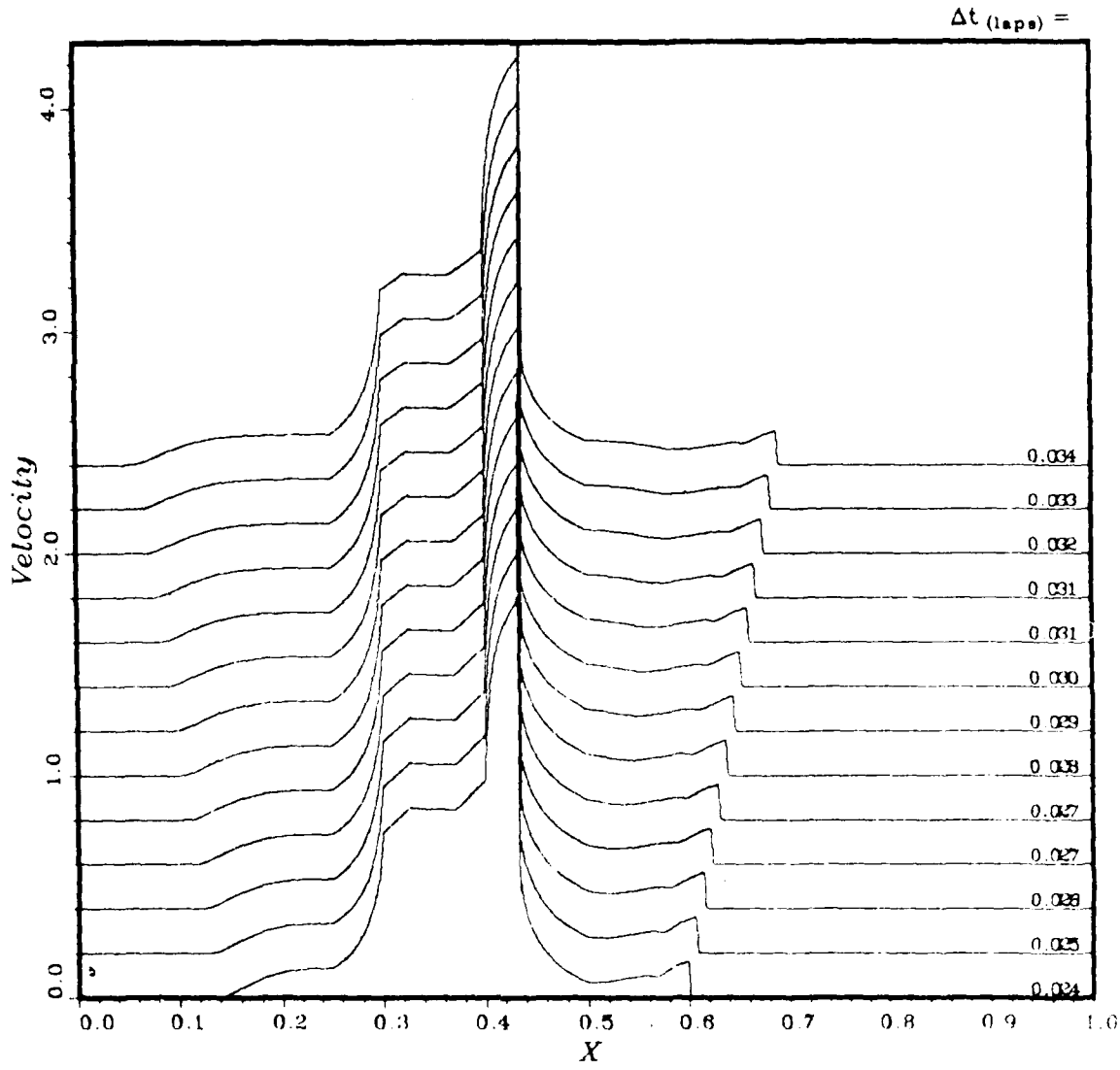


Figure 57. Detail study, magnified velocity versus distance, part 3

sound speed

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 1.500

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

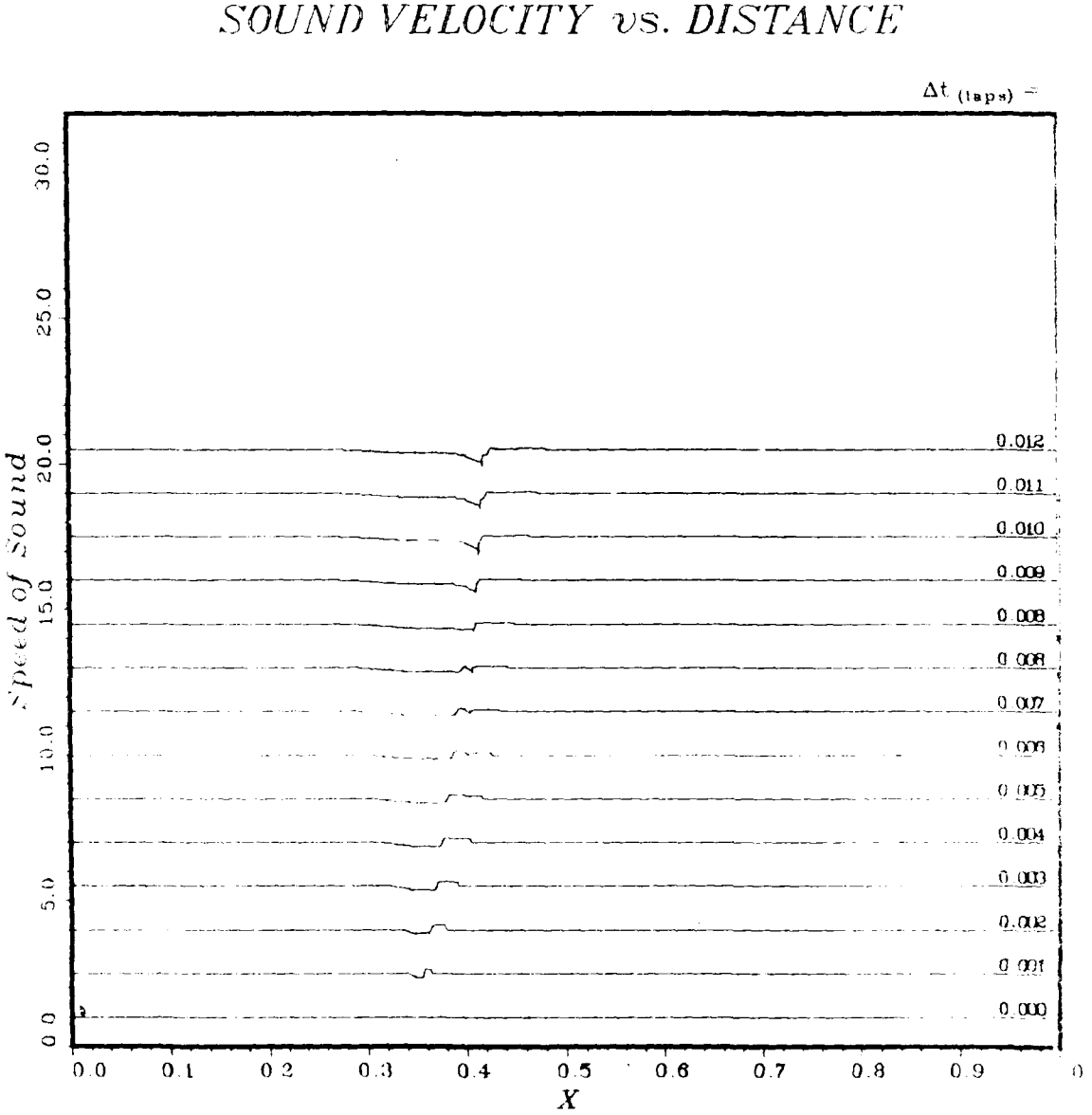


Figure 58. Detail study, sound speed versus distance, part 1

sound speed

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 1.500

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

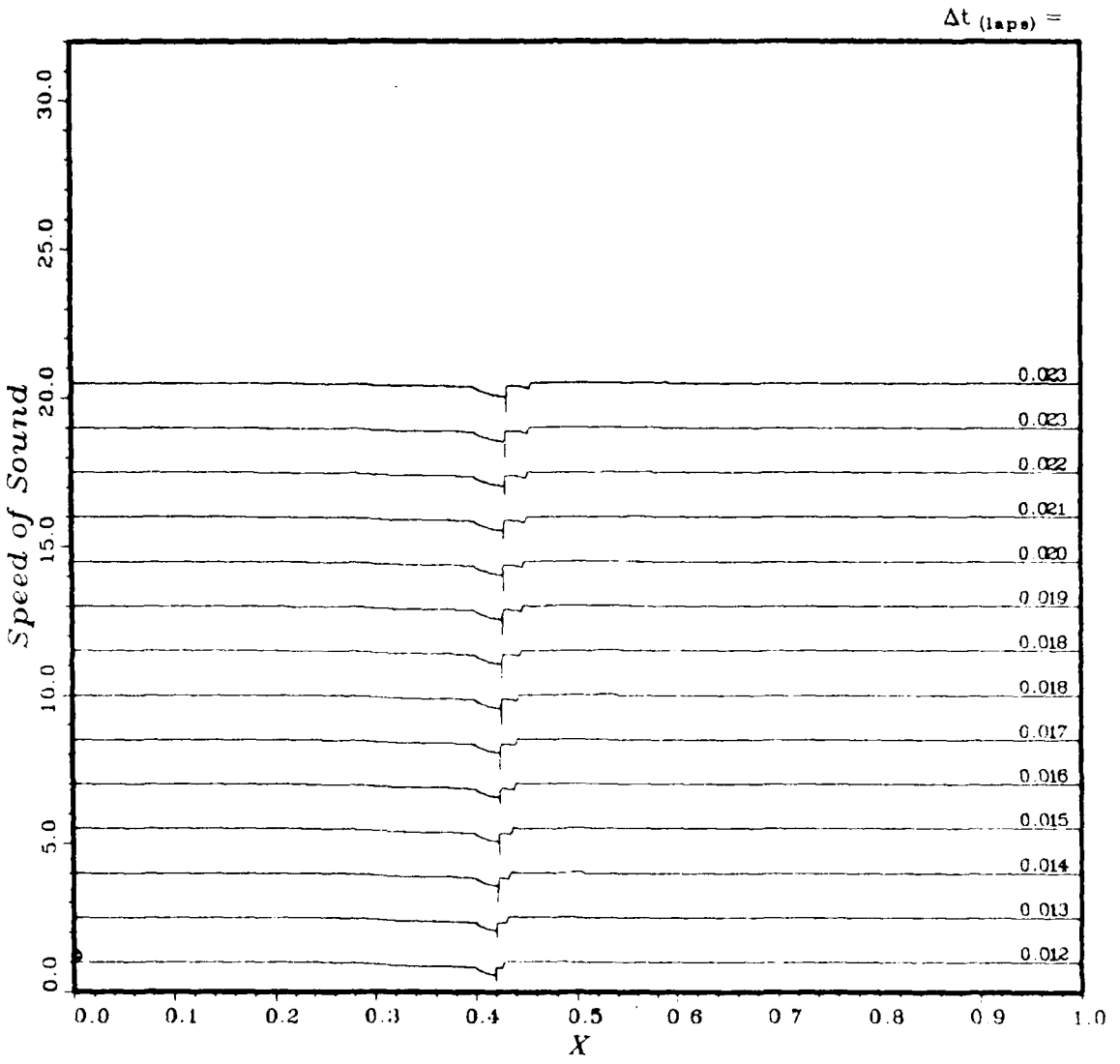


Figure 59. Detail study, sound speed versus distance, part 2

sound speed

CASE~ 8h: BRL8 - PLOT 3
Offset, Δy = 1.500

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

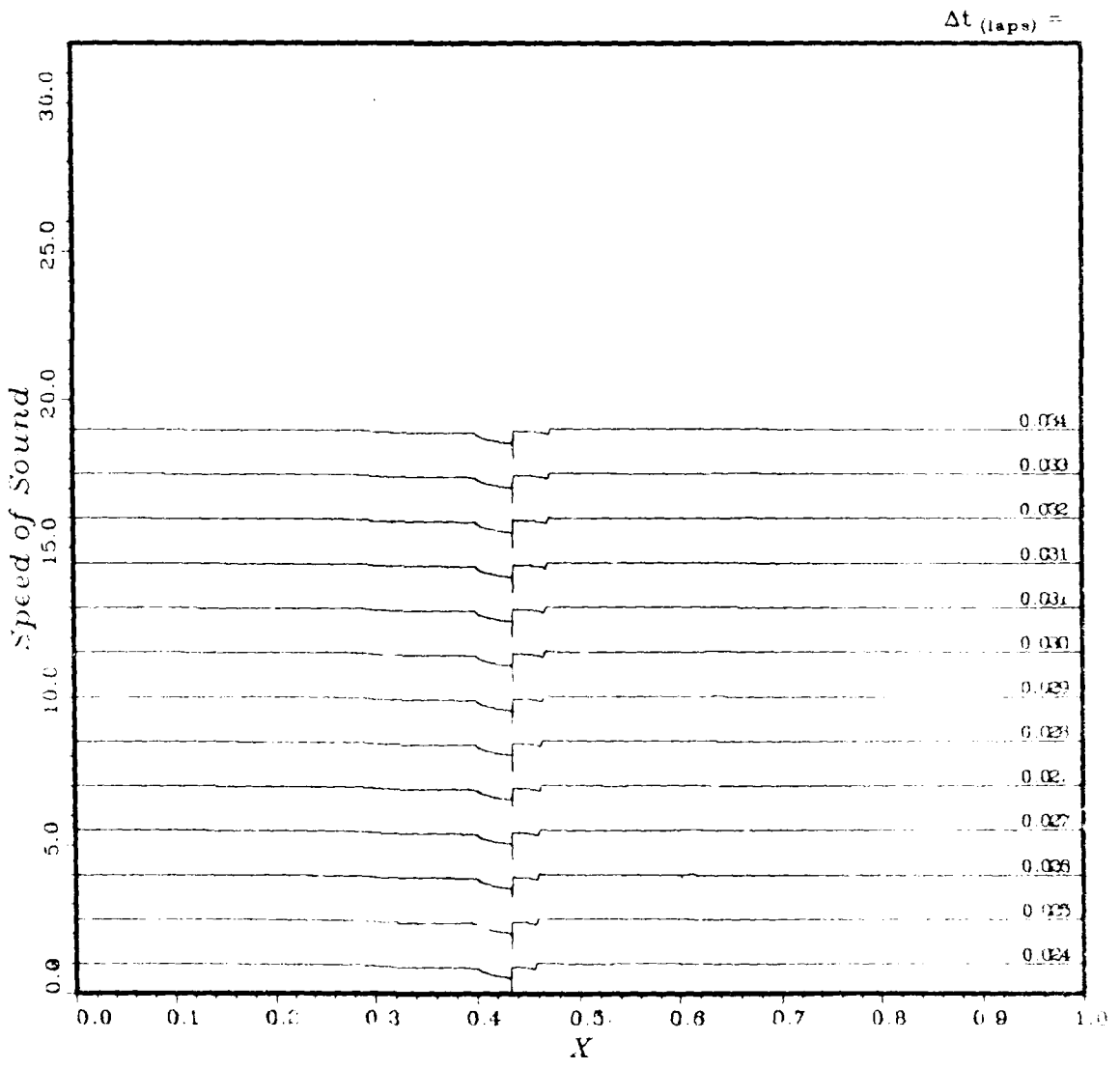


Figure 60. Detail study, sound speed versus distance, part 3

sound speed

CASE~ 8h: BRL8 - PLOT
Offset, Δy = 0.0

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{4i} = 7.000; Γ_{4i} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

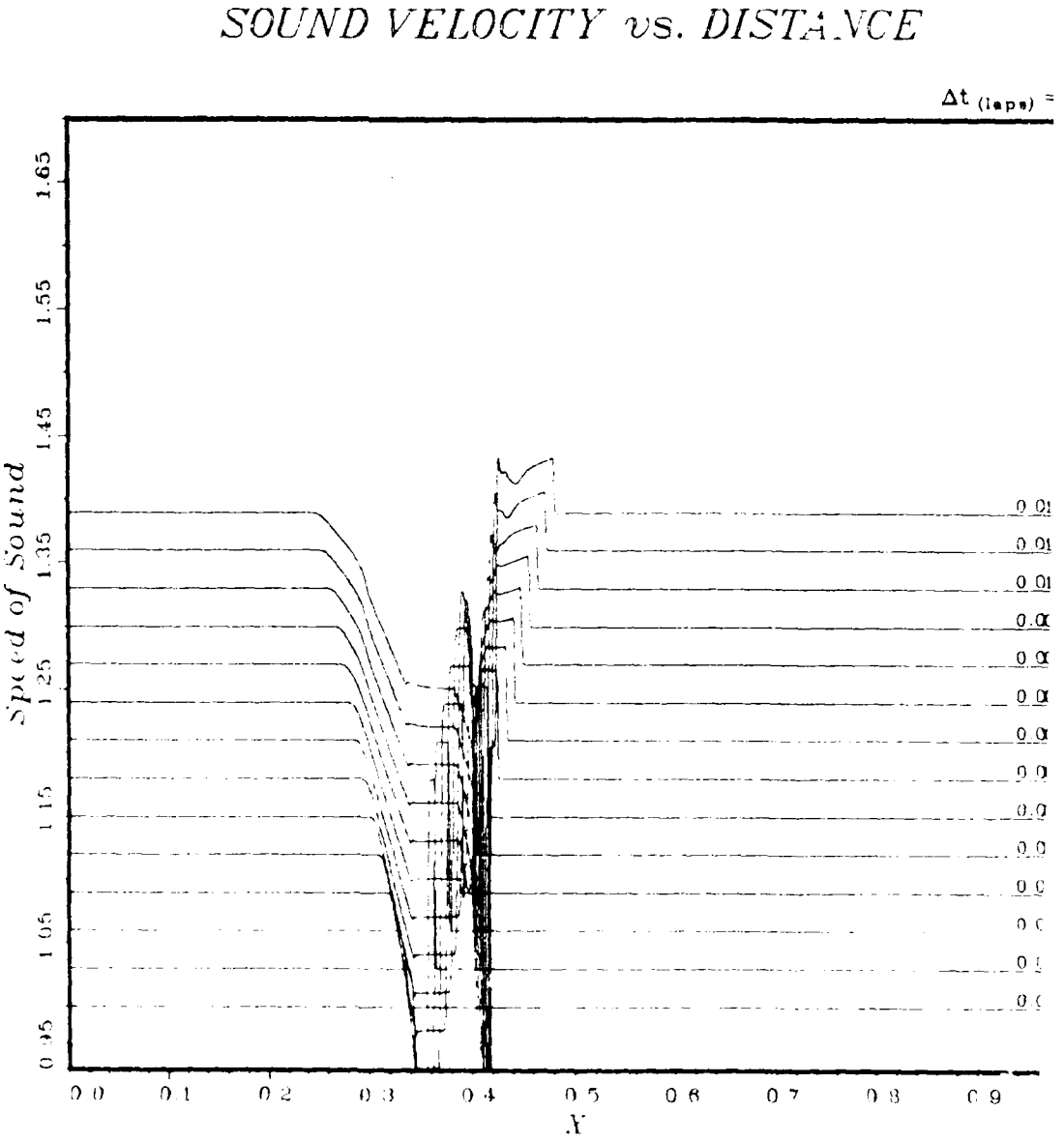


Figure 61. Detail study, magnified sound speed versus distance, part 1

sound speed

CASE~ 8h: BRI.8 PLOT 2
Offset, Δy = 0.030

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

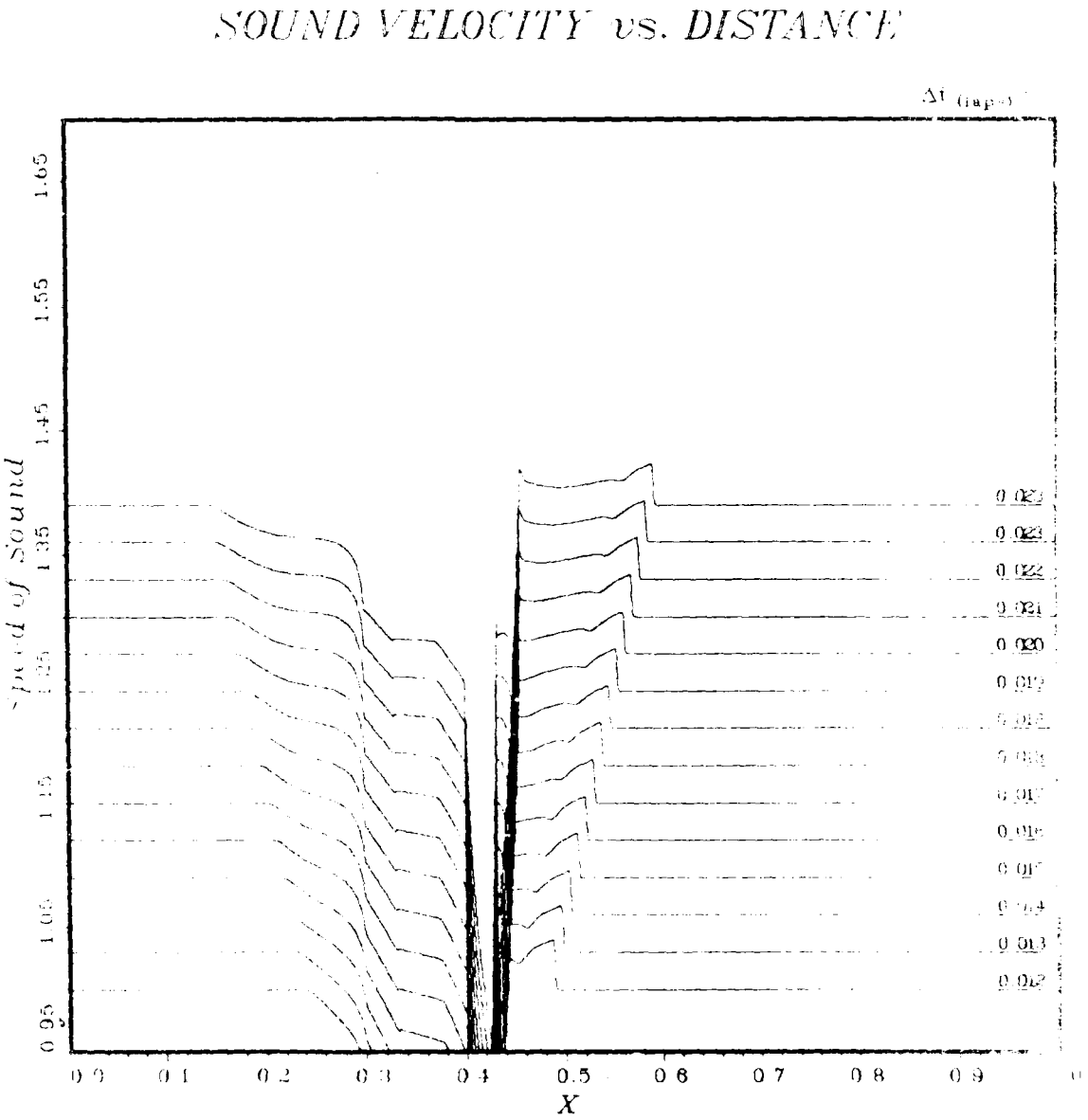


Figure 62. Detail study, magnified sound speed versus distance, part 2

sound speed

CASE~ 8h: BRL8 – PLOT 3
Offset, Δy = 0.030

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_j$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

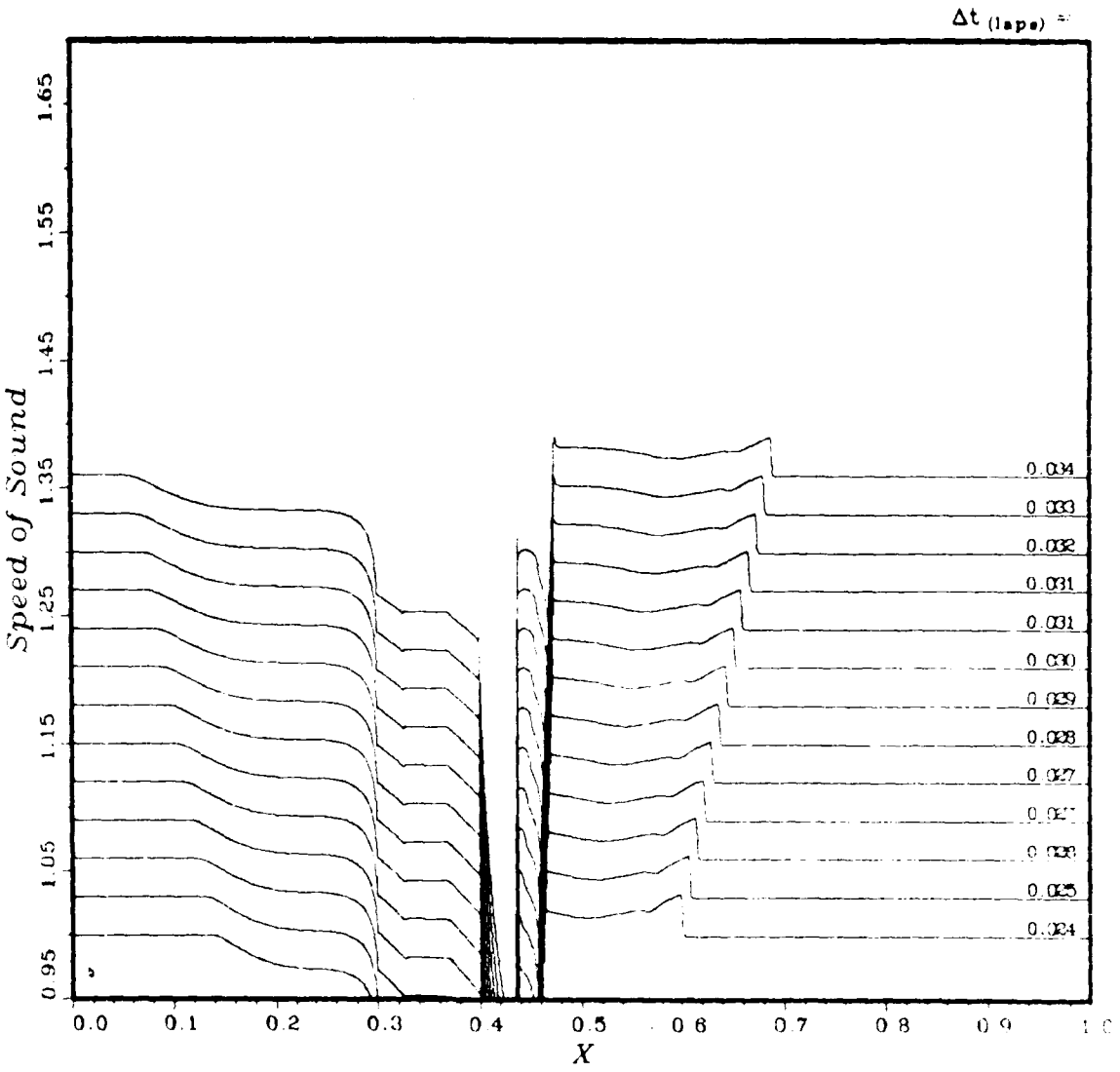


Figure 63. Detail study, magnified sound speed versus distance, part 3

pressure

CASE~ 8h: BRL8 - PLOT
Offset, Δy = 1.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_1$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

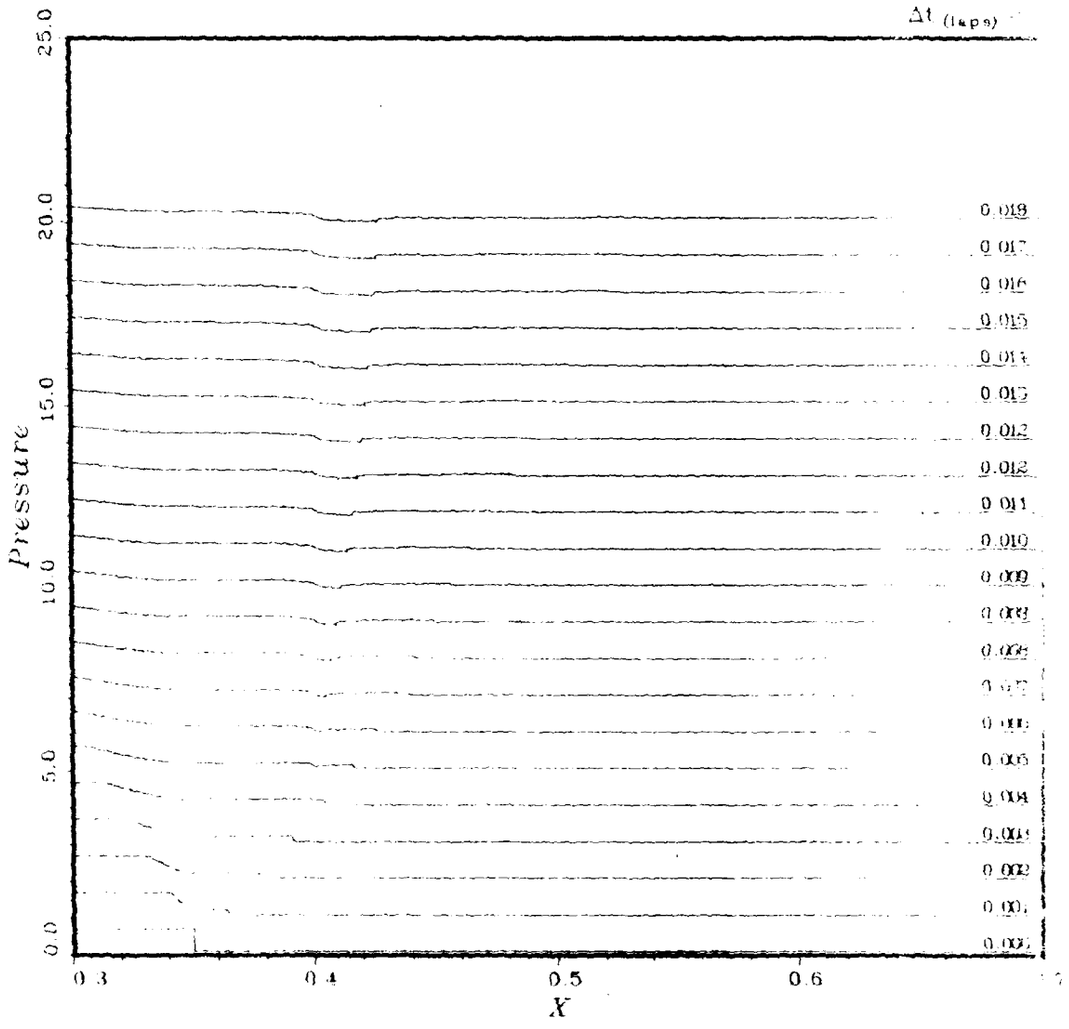


Figure 64. Detail study, pressure versus distance 0.3 to 0.7, part 1

pressure

CASE~ 8h: BRL8 ~ PLOT
Offset, Δy = 1.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_j$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

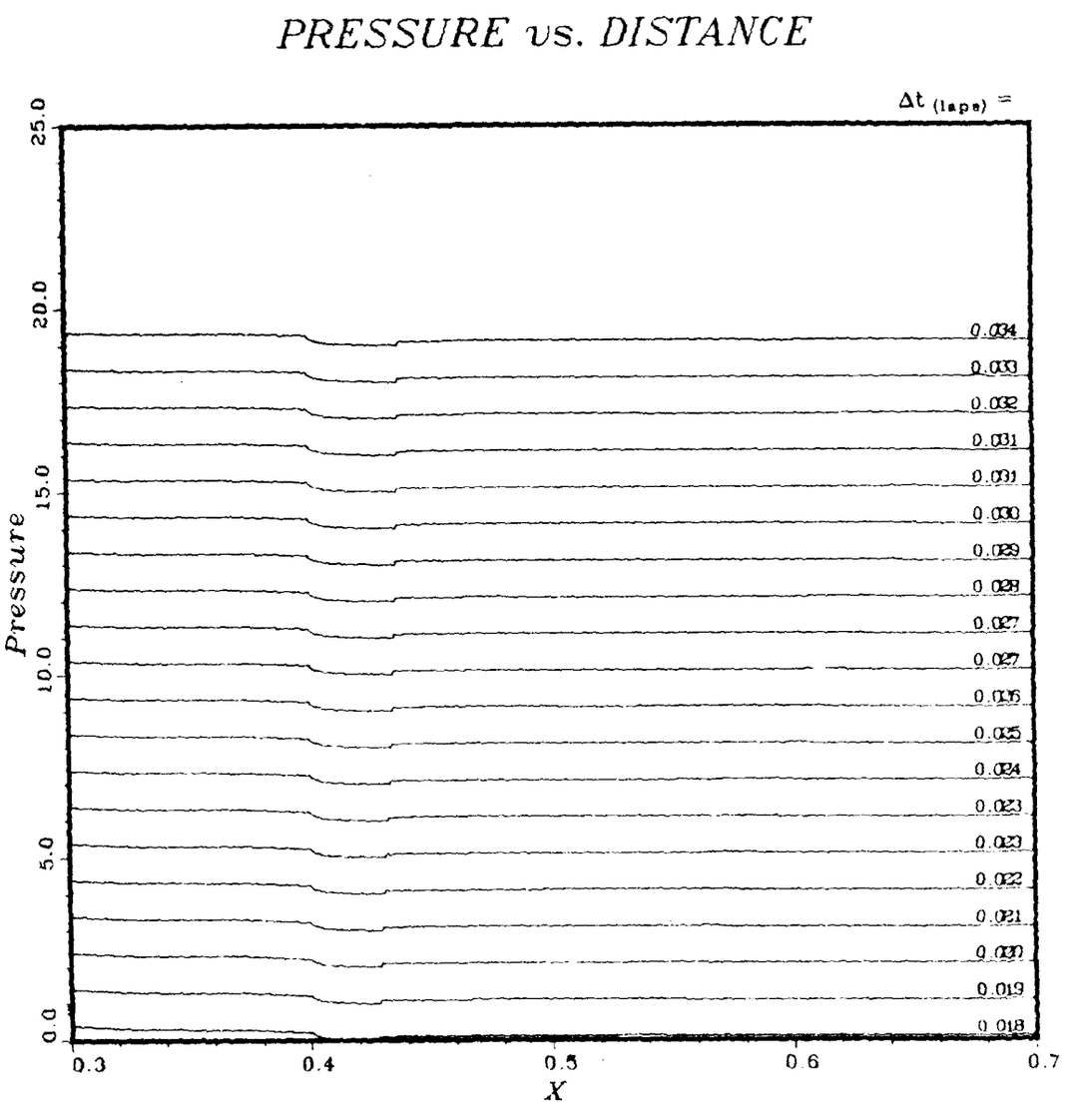


Figure 65. Detail study, pressure versus distance 0.3 to 0.7, part 2

pressure

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.030

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

PRESSURE vs. DISTANCE

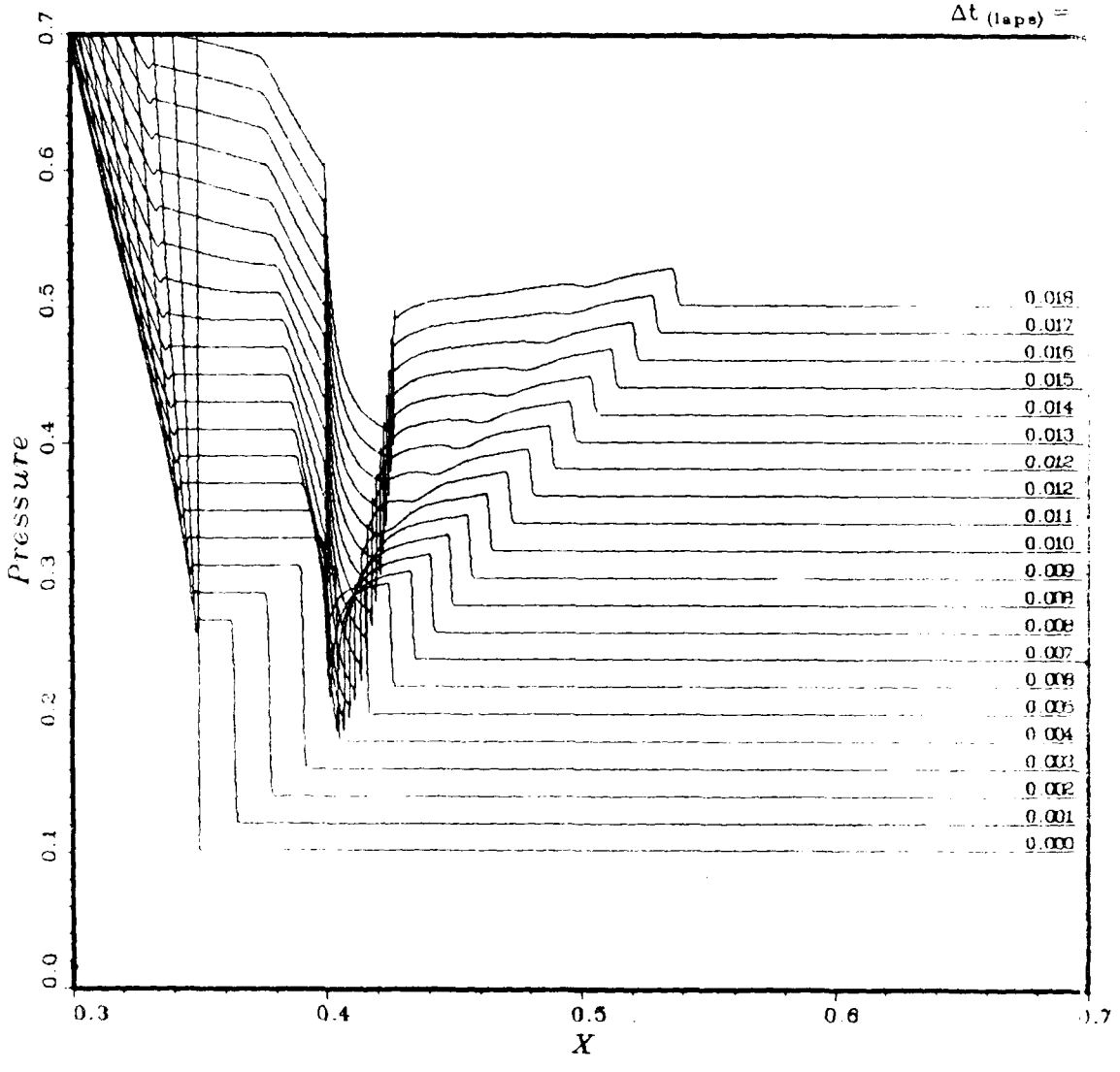


Figure 66. Detail study, magnified pressure versus distance 0.3 to 0.7, part 1

pressure

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
$P_{\phi 1}$ = 7.000; $T_{\phi 1}$ = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

PRESSURE vs. DISTANCE

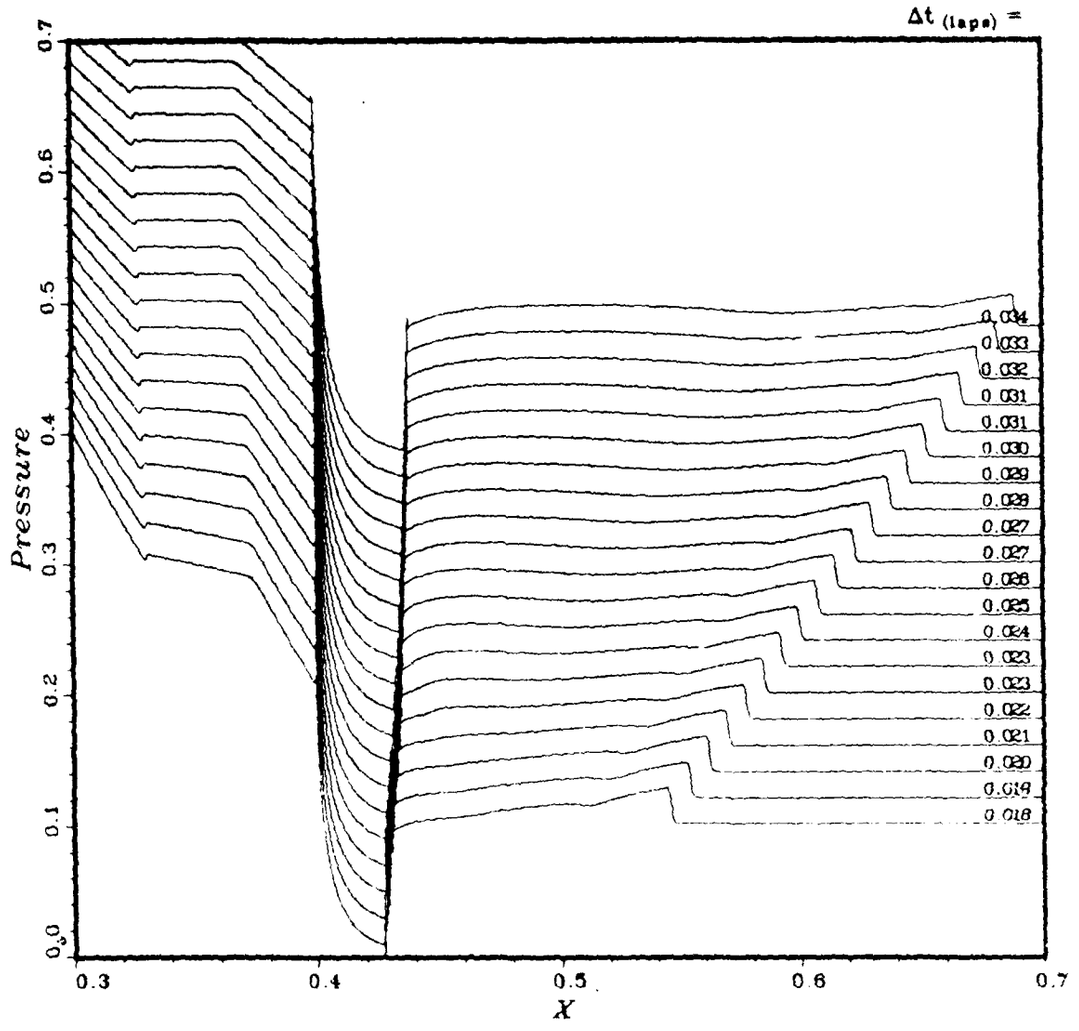


Figure 67. Detail study, magnified pressure versus distance 0.3 to 0.7, part 2

density

CASE~ 8h: BRL8 – PLOT 1
Offset, Δy = 0.100

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

DENSITY vs. DISTANCE

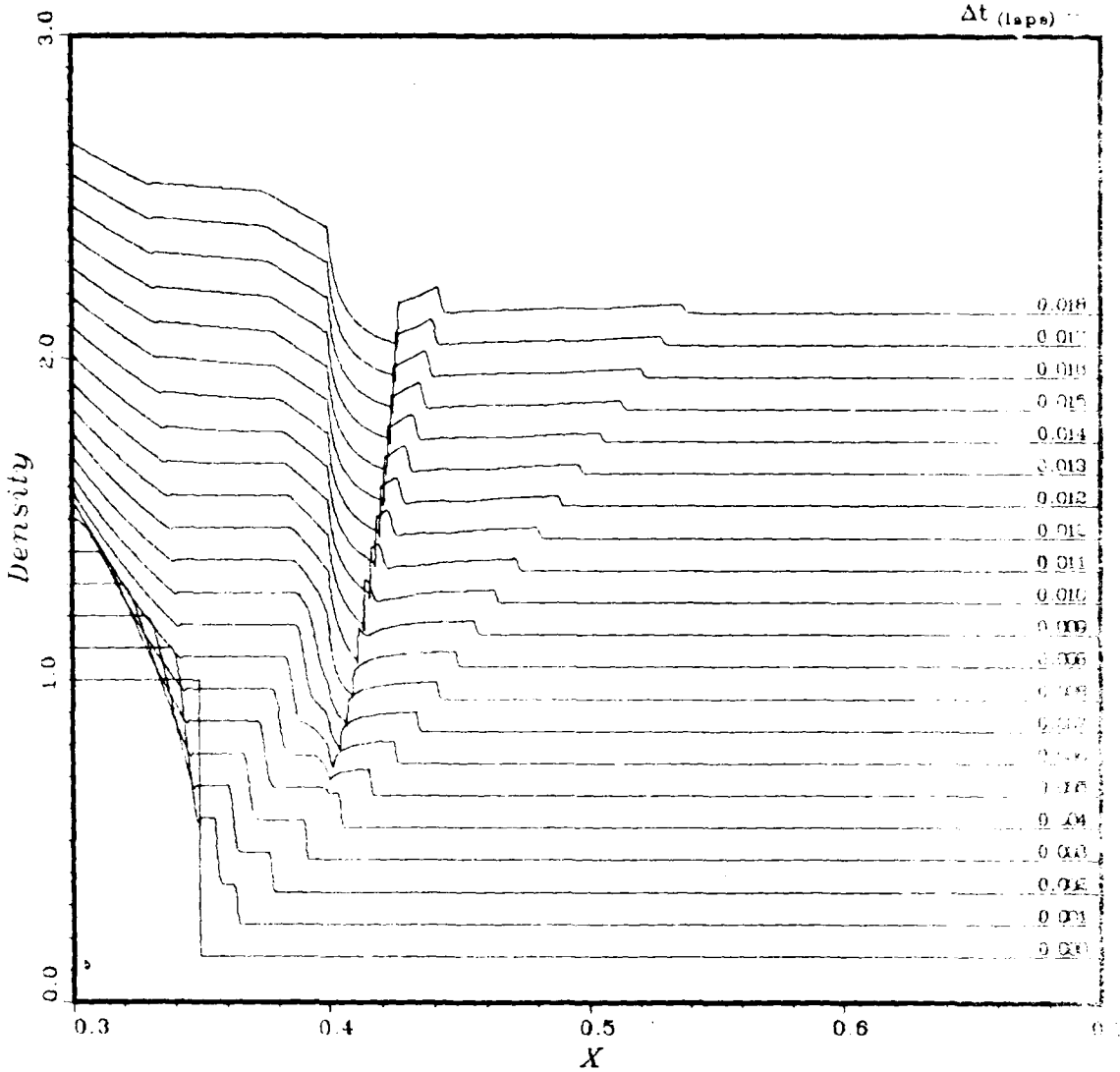


Figure 68. Detail study, density versus distance 0.3 to 0.7, part 1

density

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.560, 0.600, 0.700

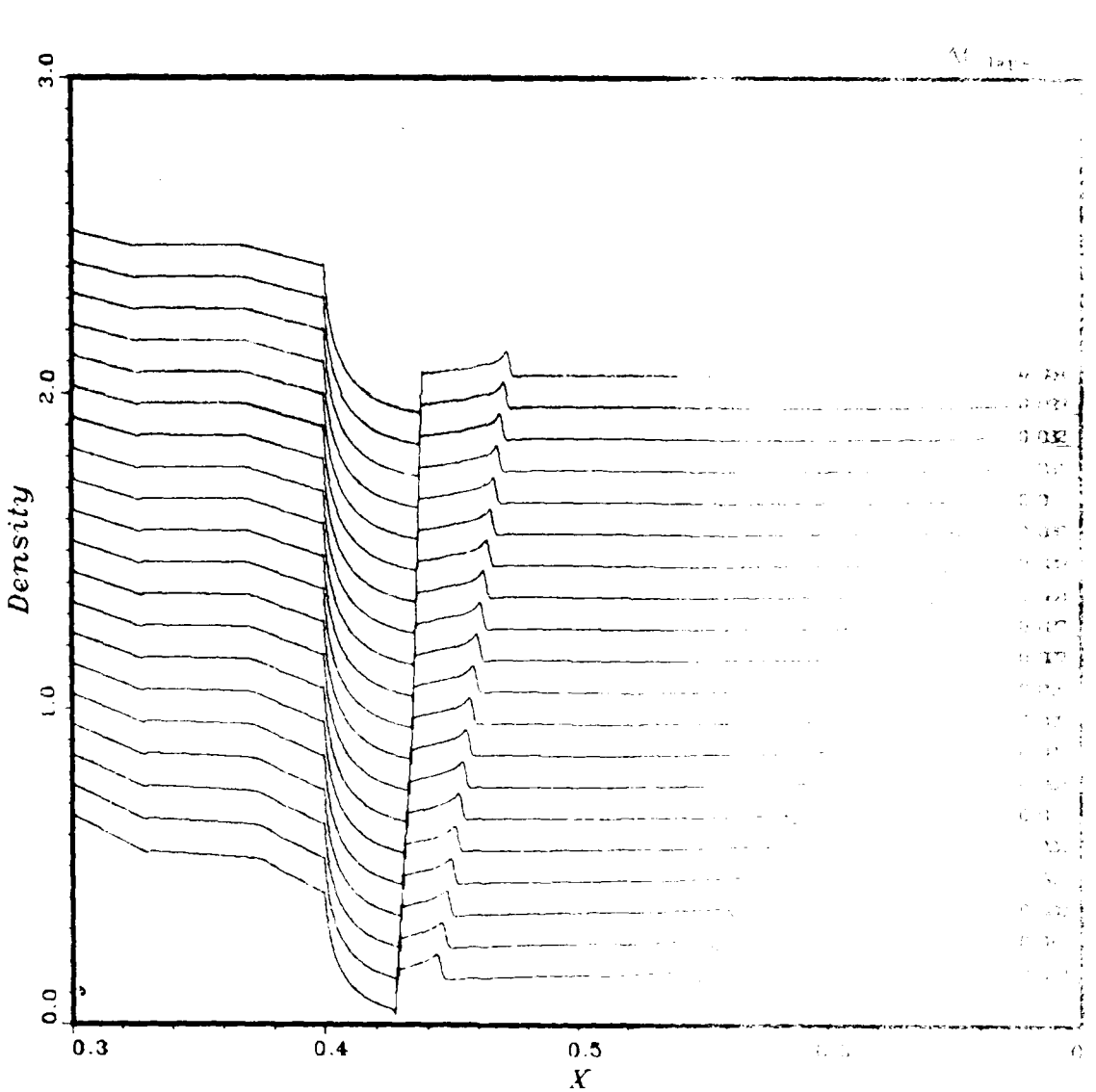


Figure 69. Detail study, density versus distance 0.3 to 0.7, part 2

PLOT 9 19.40.36 MON 21 DEC, 1987 JOB-P1045985, ISSCO DISSPLA 10.0

density

CASE~ 8h: BRL8 -- PLOT 1
Offset, Δy = 0.010

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

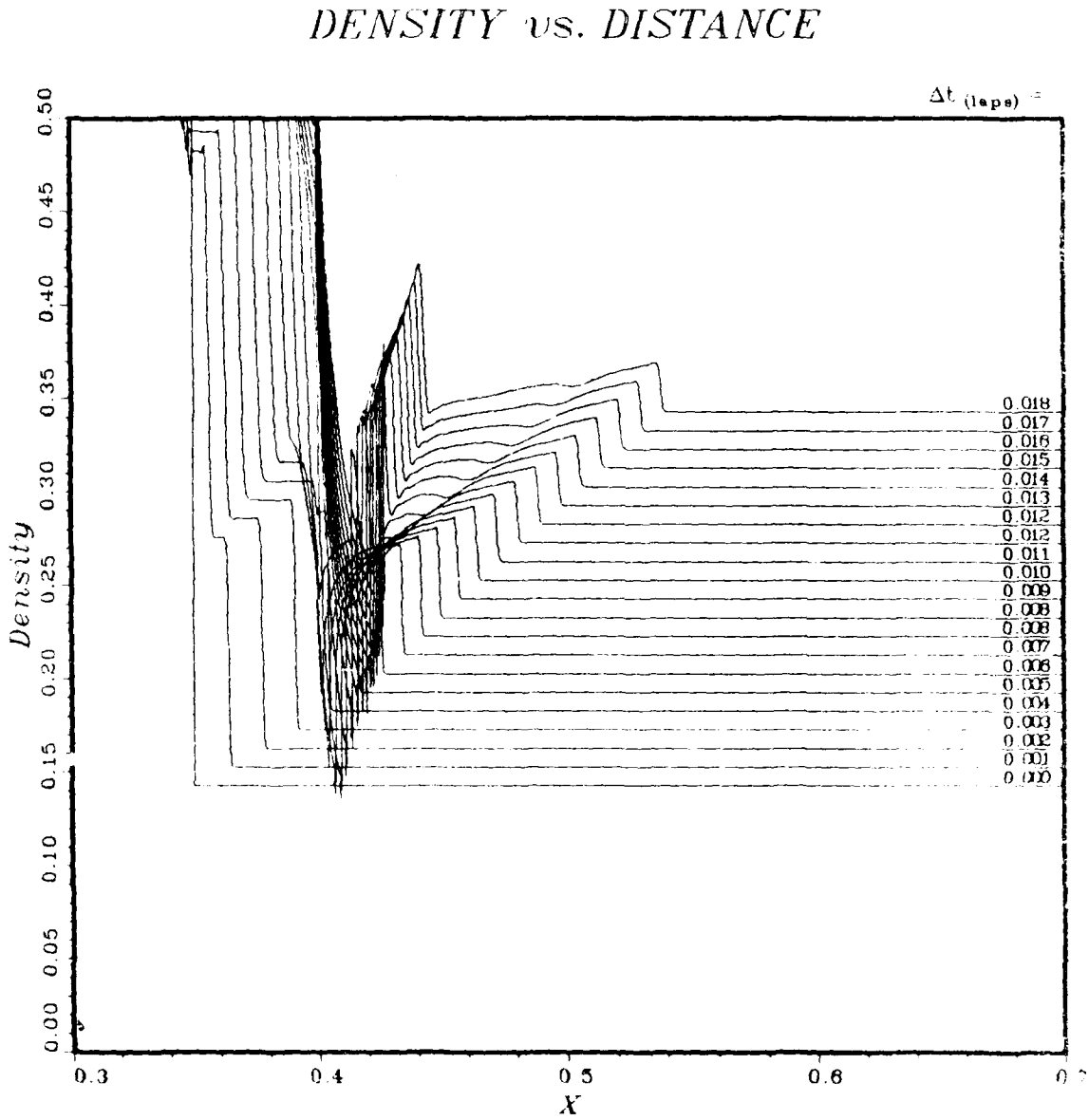


Figure 70. Detail study, magnified density versus distance 0.3 to 0.7, part 1

density

CASE~ 8h: BRL8 - PL
Offset, Δy = 0.01

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

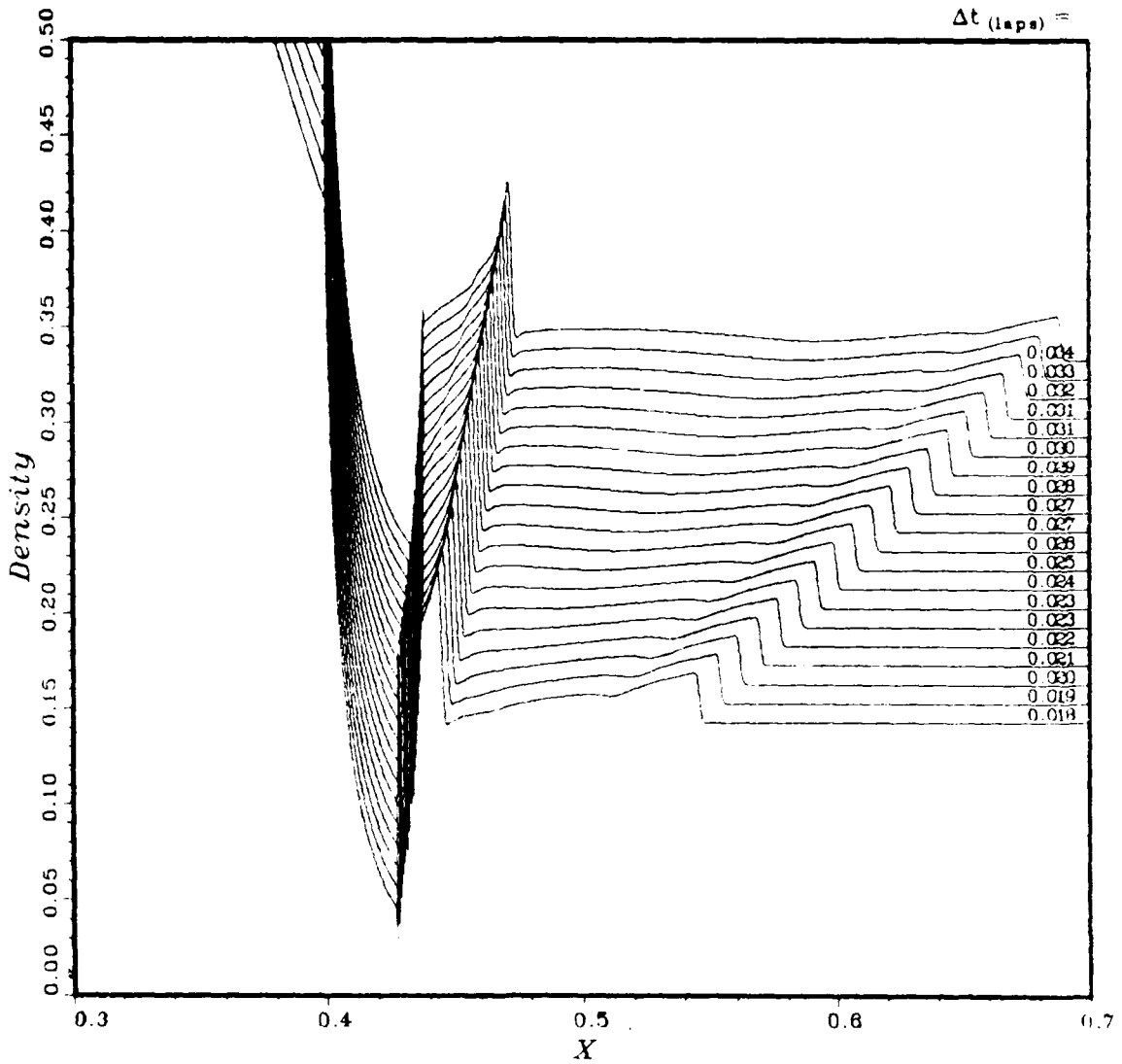


Figure 71. Detail study, magnified density versus distance 0.3 to 0.7, part 2

PLOT 7 .9.40.13 MON 21 DEC, 1987 JOB-P1045985, ISSCO DISSPLA 10.0

velocity

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 3.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

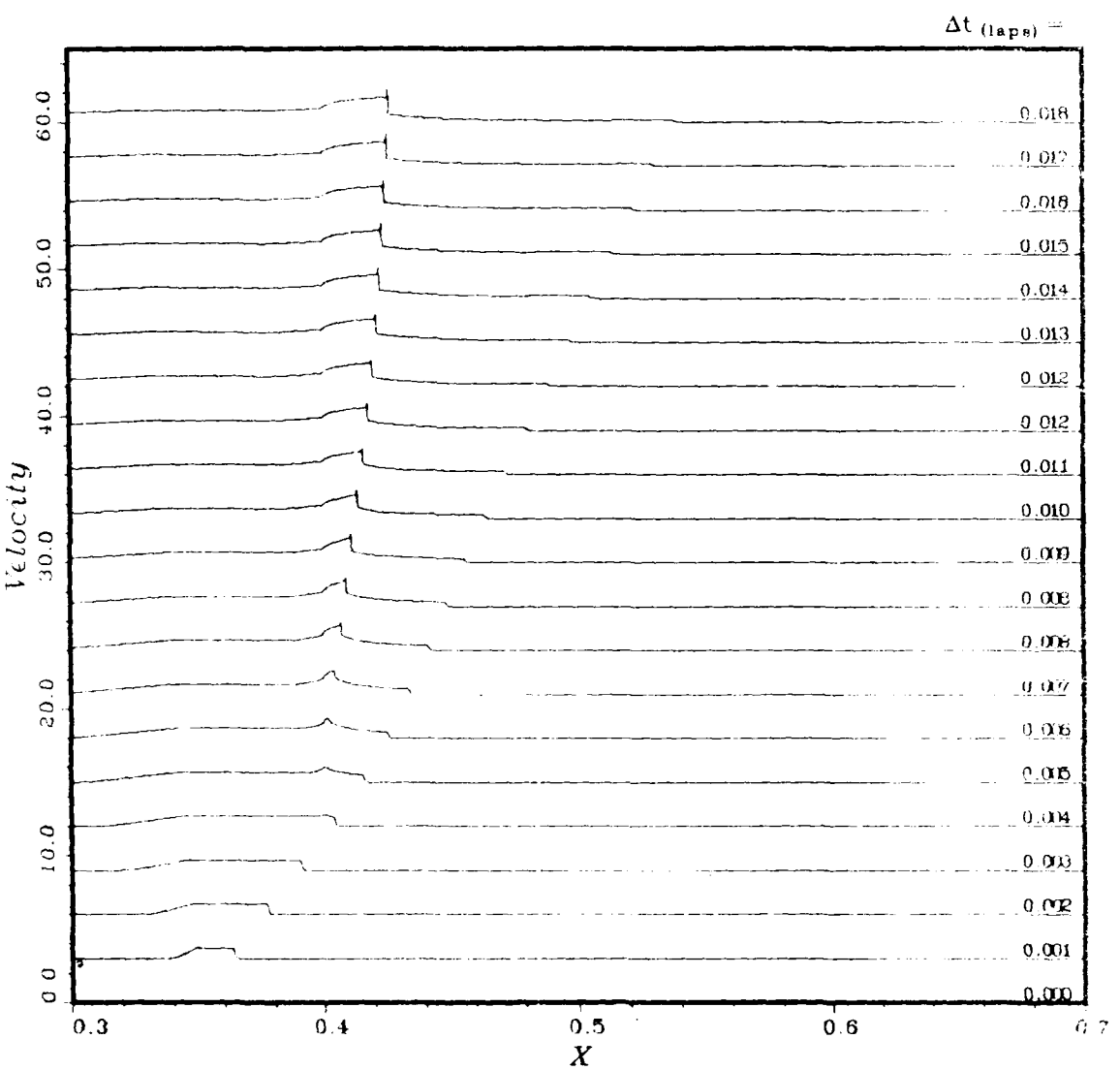


Figure 72. Detail study, velocity versus distance 0.3 to 0.7, part 1

velocity

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 3.000

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_1$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

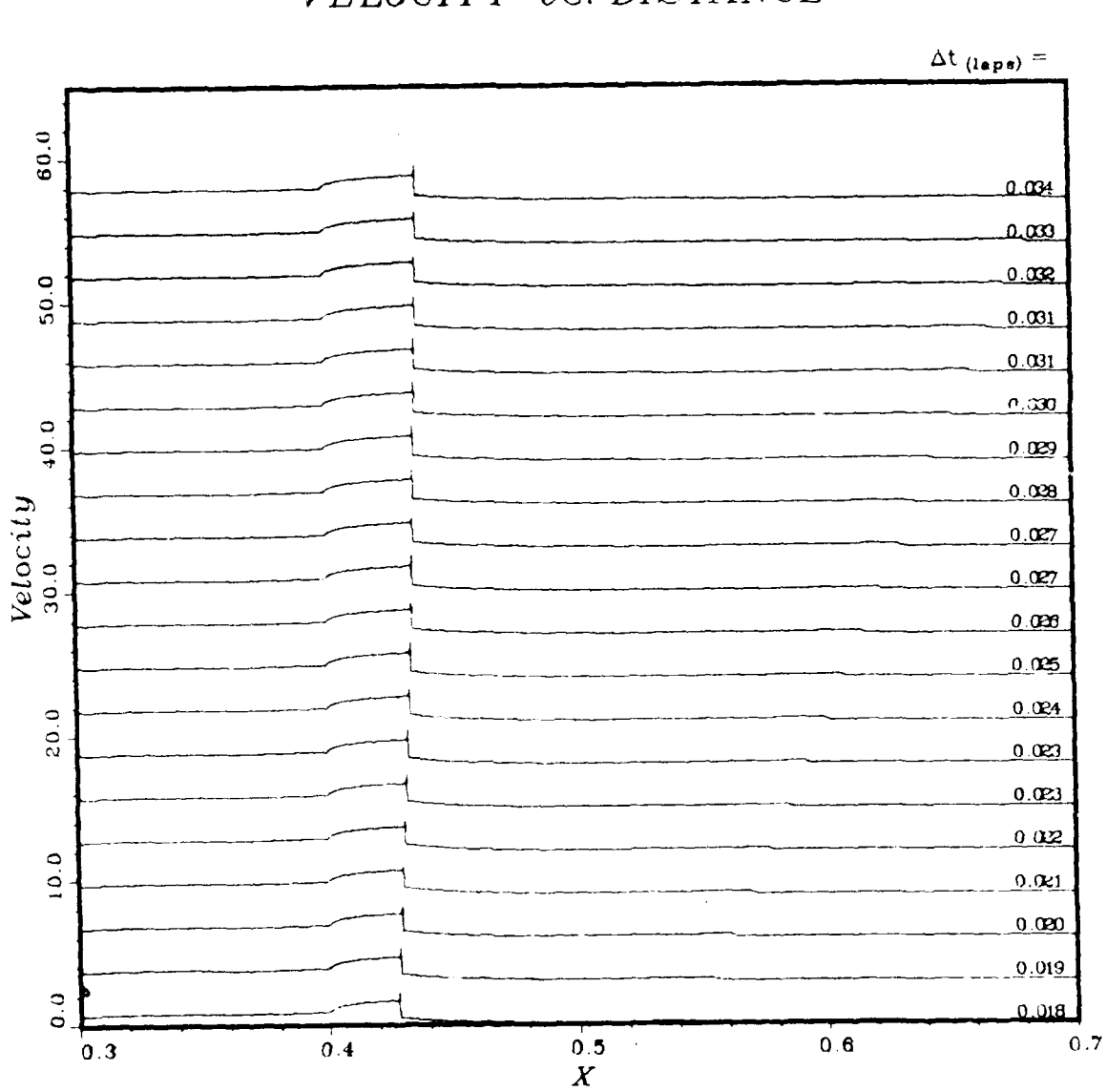


Figure 73. Detail study, velocity versus distance 0.3 to 0.7, part 2

PLOT 13 19.41.41 MON 21 DEC, 1987 JOB=PIC45985, ISSDG DISSPLA 10.0

velocity

CASE~ 8h: BRL8 PLOT 1
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_j$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

VELOCITY vs. DISTANCE

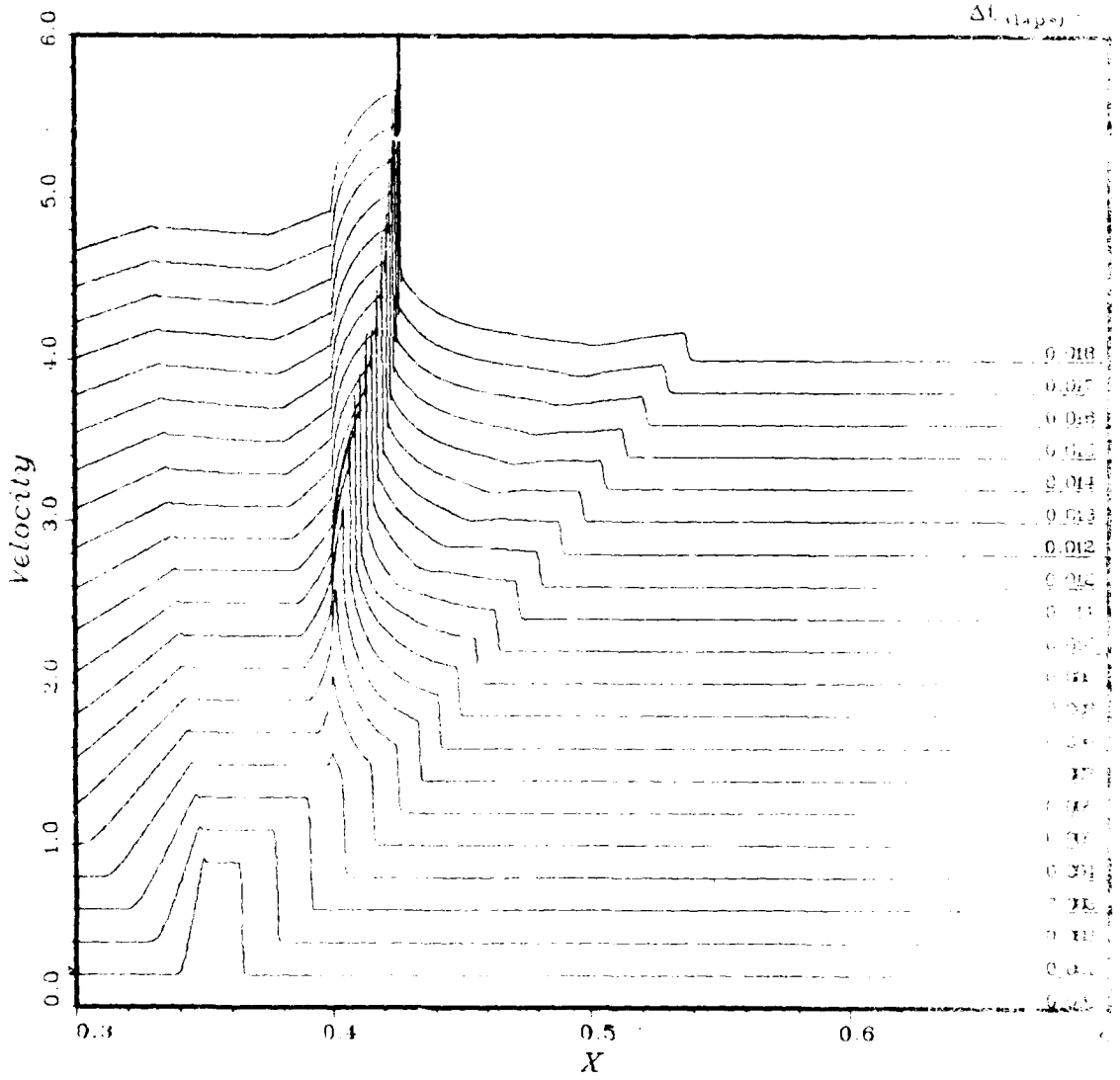


Figure 74. Detail study, magnified velocity versus distance 0.3 to 0.7, part 1

velocity

CASE~ 8h: BRL8 ~ PLOT 2
Offset, $\Delta y = 0.200$

$L_{ref} = 40.00\ m$
$V_{drv} = 276.1\ m^3$
$P_{41} = 7.000$; $T_{41} = 1.000$
$XSTA_1 = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700$

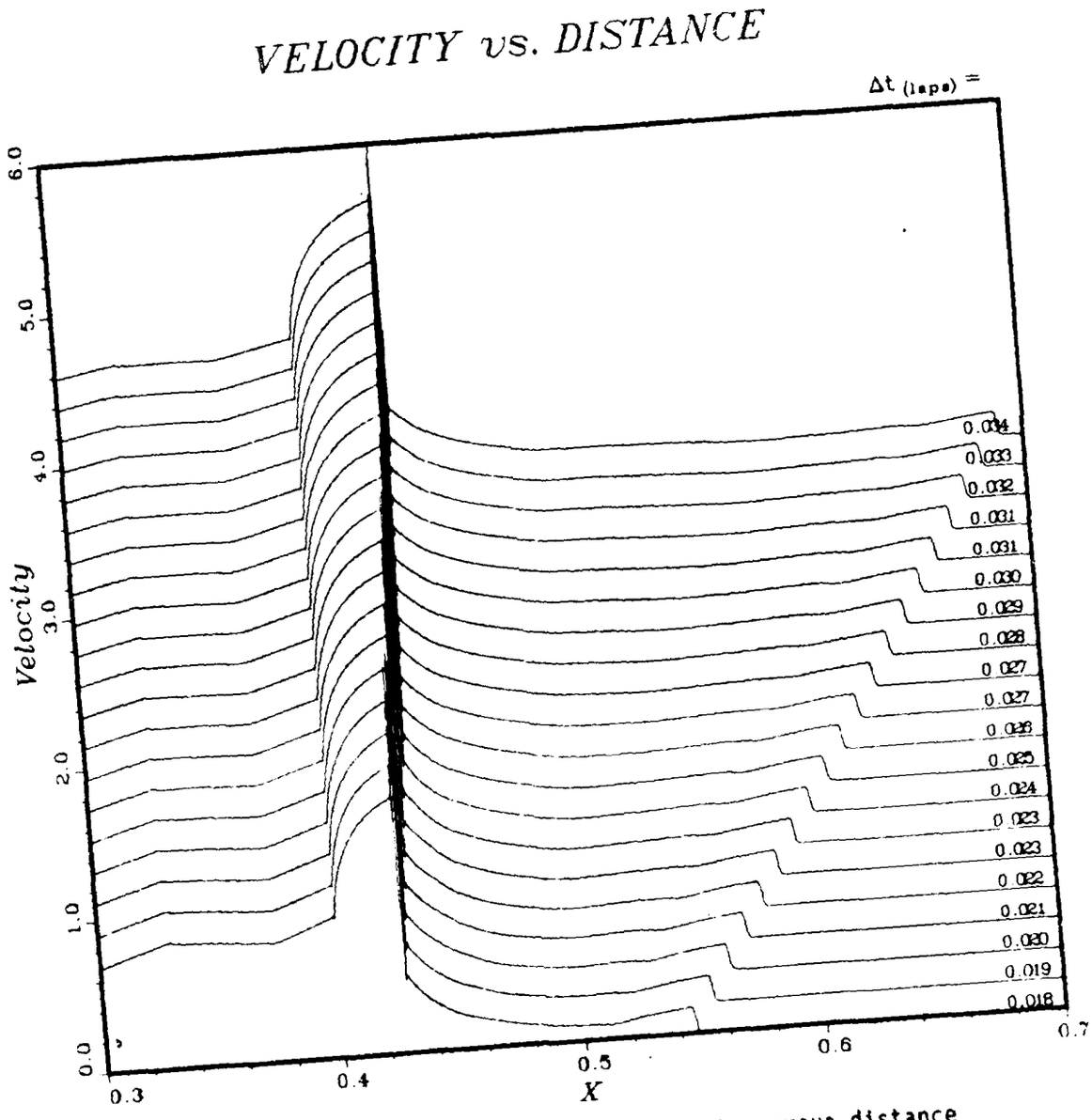


Figure 75. Detail study, magnified velocity versus distance 0.3 to 0.7, part 2

sound speed

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 1.500

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

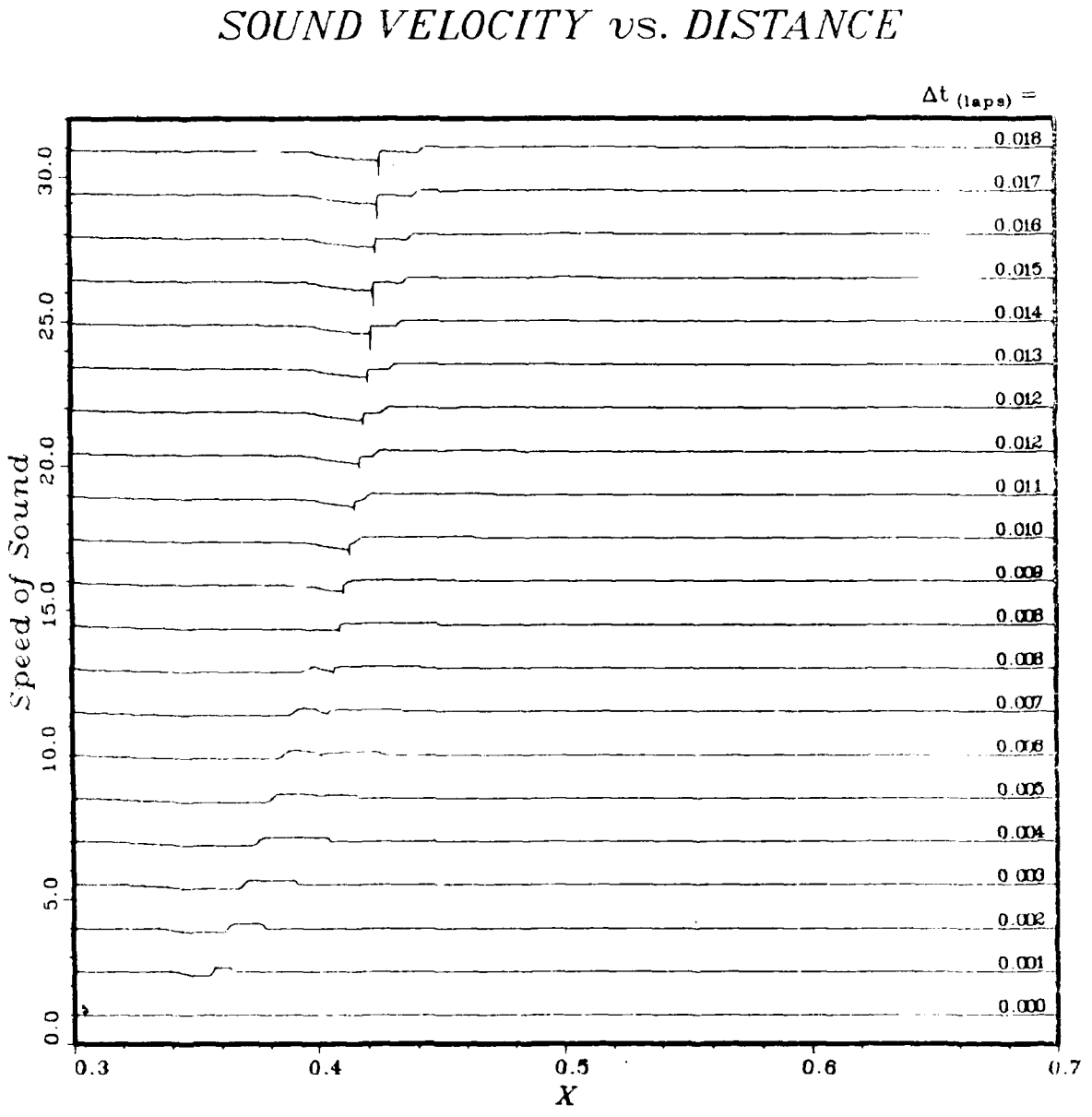
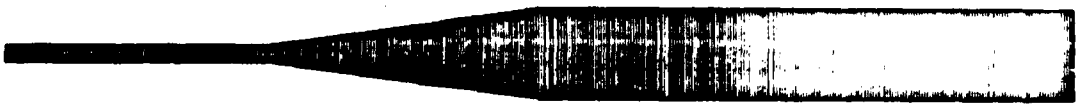


Figure 76. Detail study, sound speed versus distance 0.3 to 0.7, part 1

sound speed

CASE~ 8h: BRL8 – PLOT 2
Offset, Δy = 1.500

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700



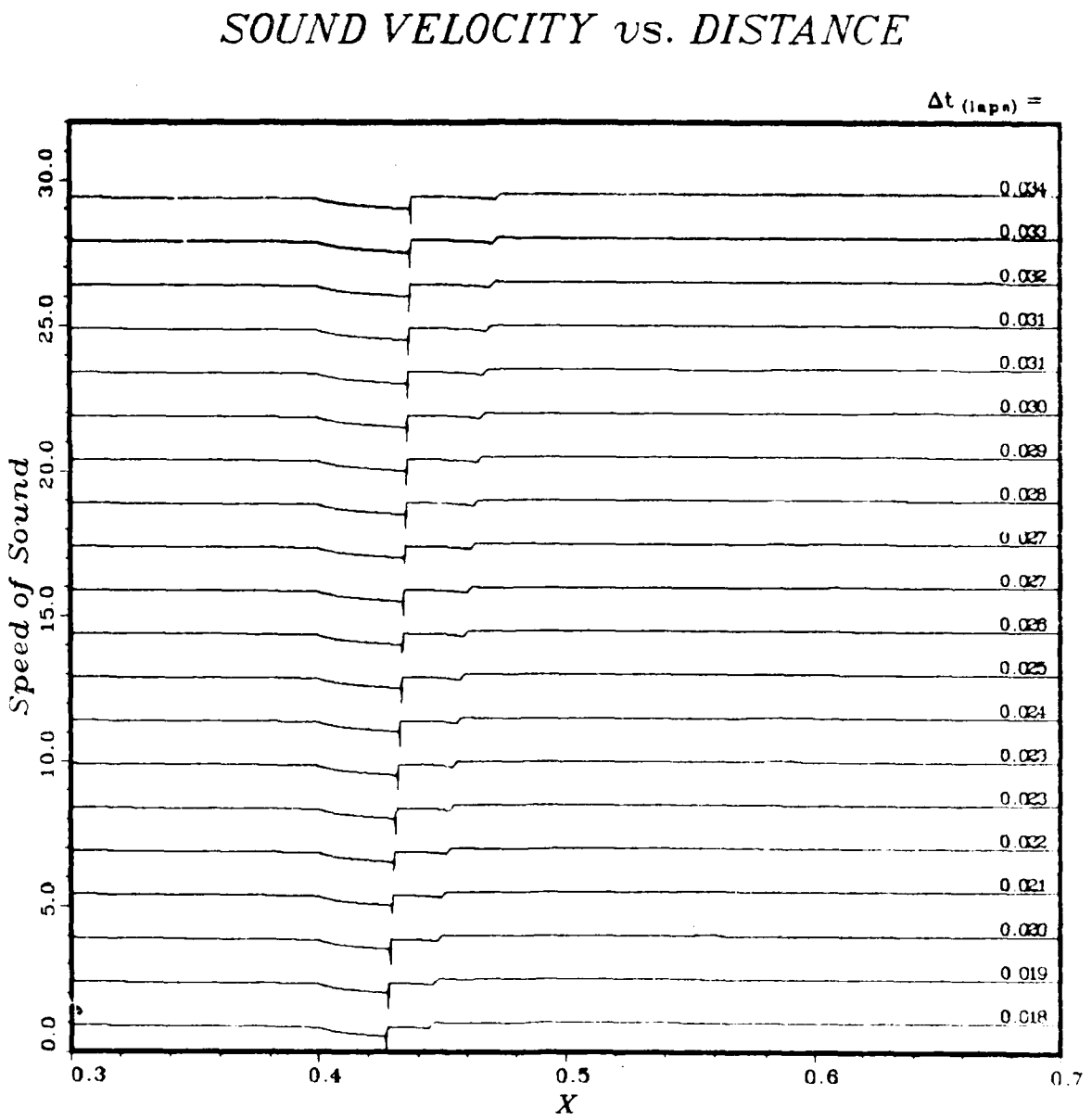


Figure 77. Detail study, sound speed versus distance 0.3 to 0.7, part 2

sound speed

CASE~ 8h: BRL8 – PLOT 1
Offset, Δy = 0.030

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

SOUND VELOCITY vs. DISTANCE

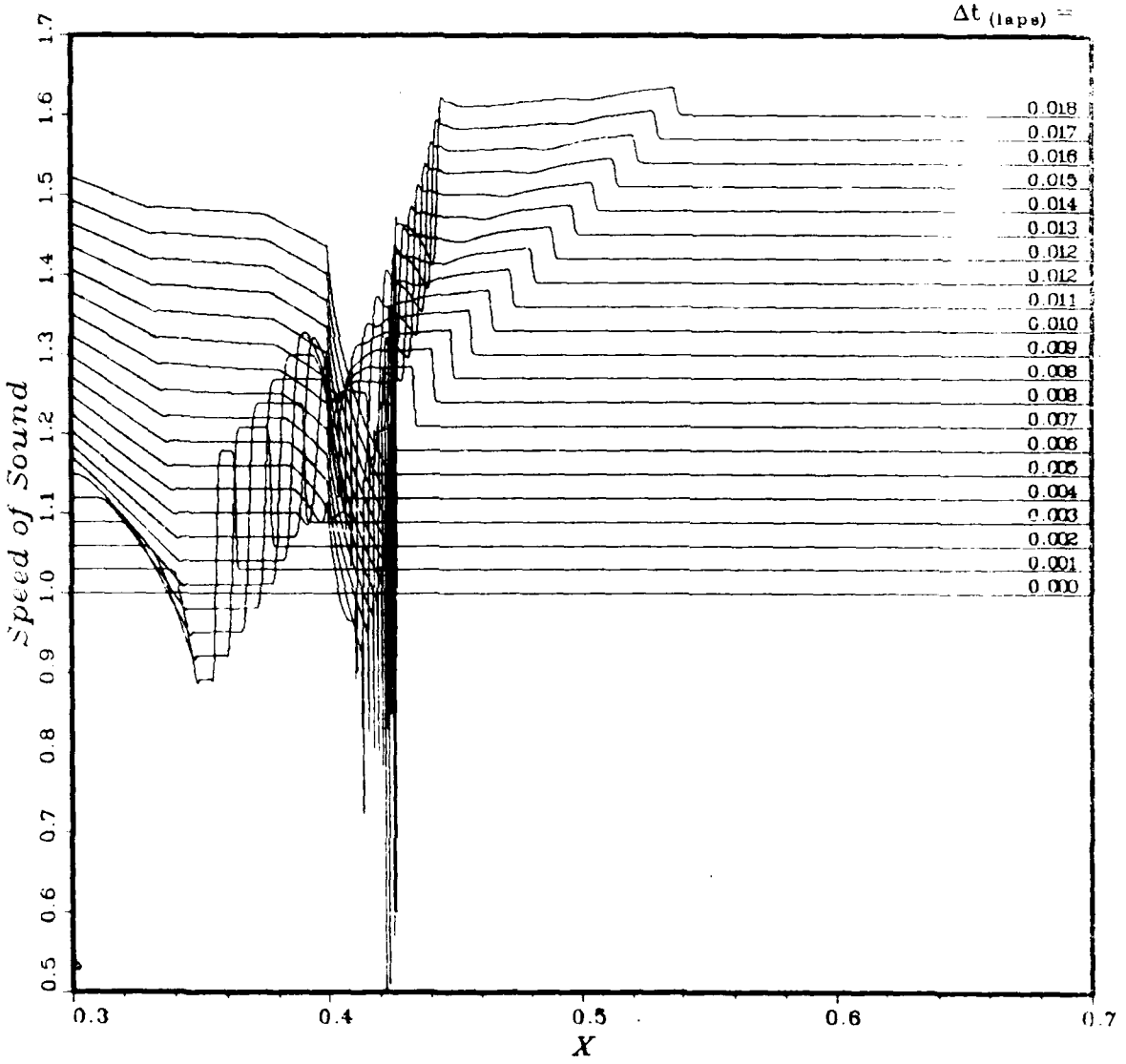
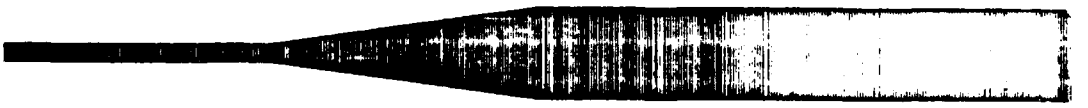


Figure 78. Detail study, magnified sound speed versus distance 0.3 to 0.7, part 1

sound speed

CASE~ 8h: BRL8 -- PLOT
Offset, Δy = 0.00

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700



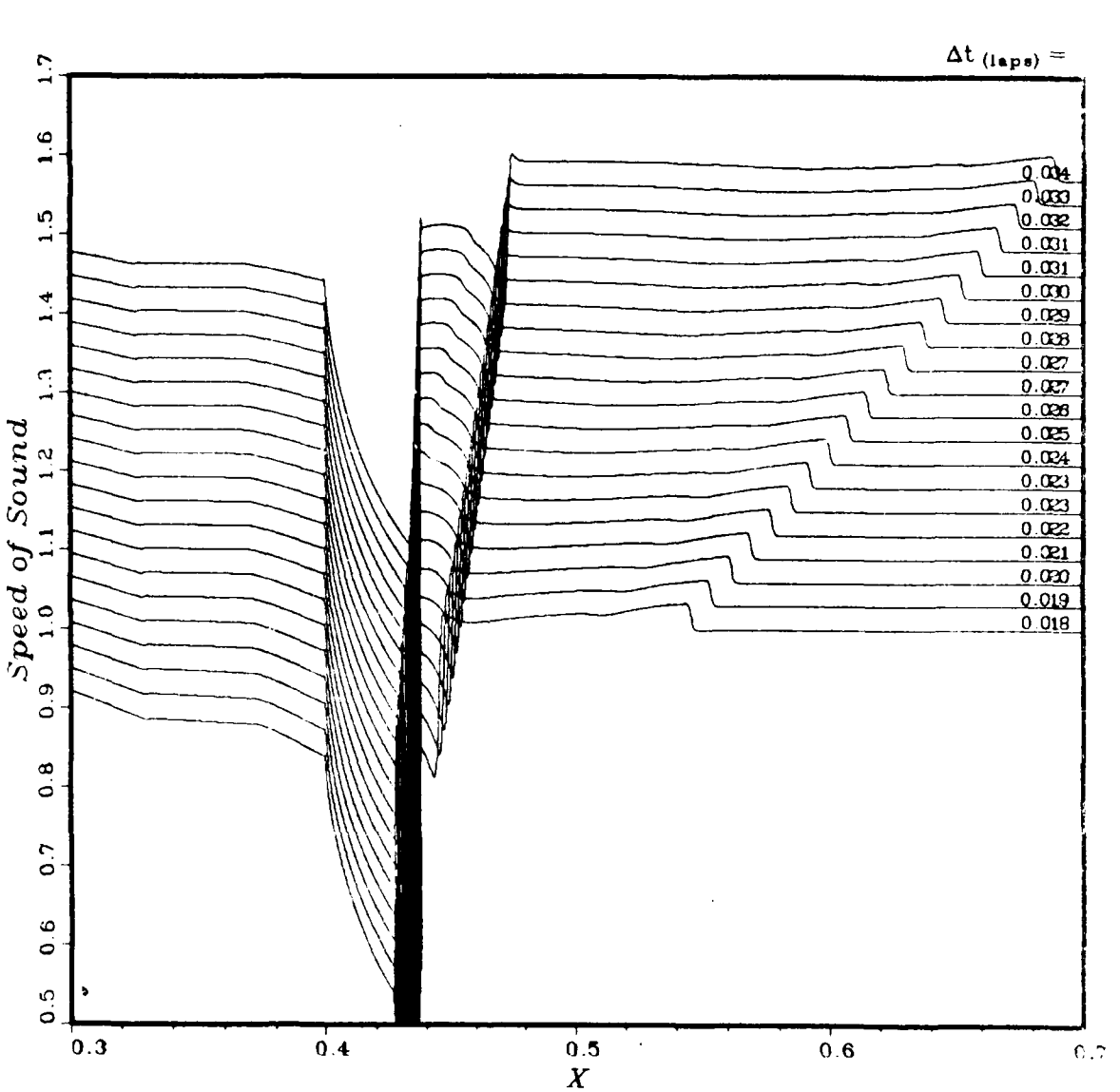


Figure 79. Detail study, magnified sound speed versus distance 0.3 to 0.7, part 2

pressure

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

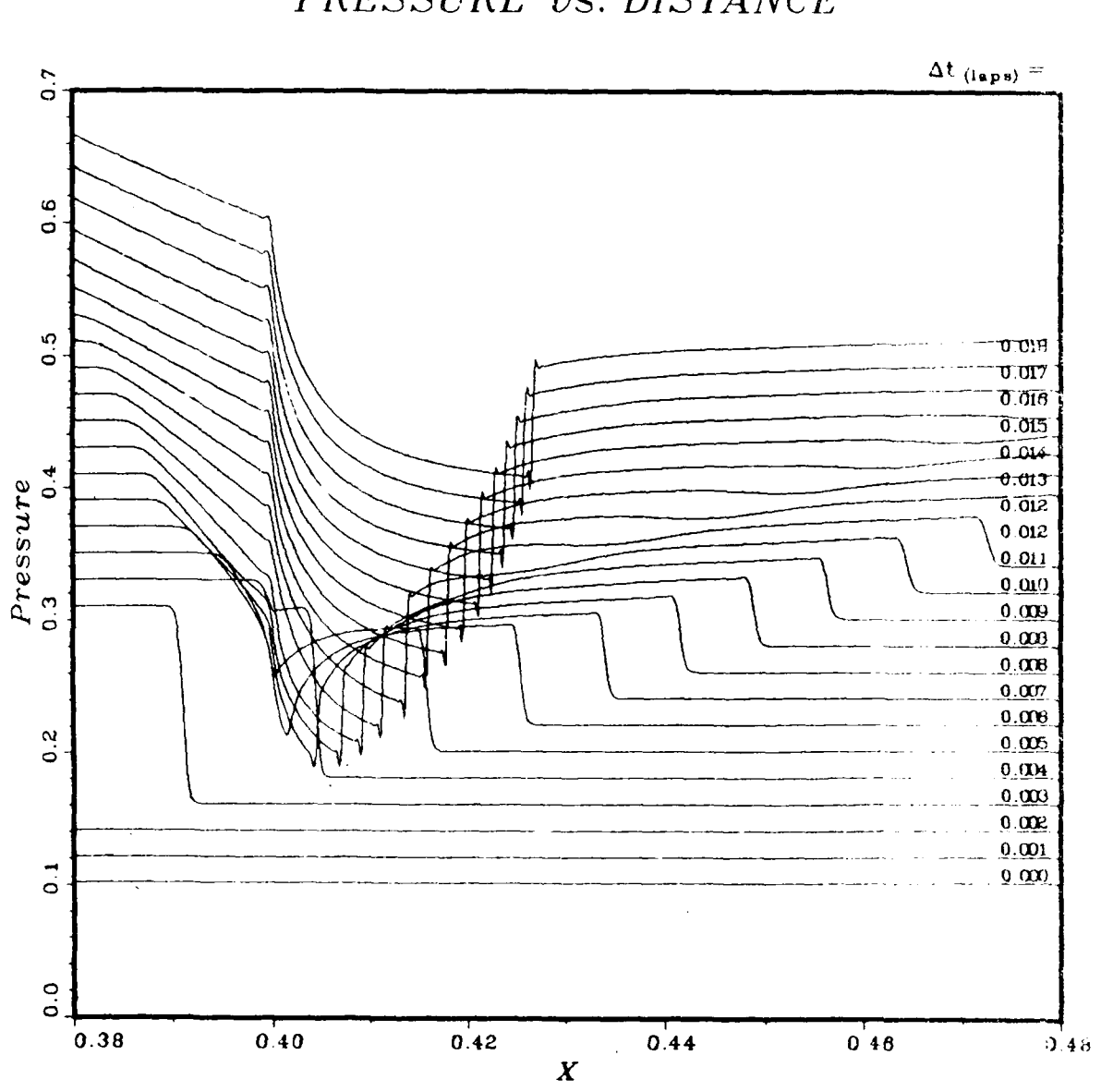


Figure 80. Detail study, pressure versus distance 0.38 to 0.48

density

CASE~ 8h: BRL8 – PLOT 1
Offset, Δy = 0.010

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

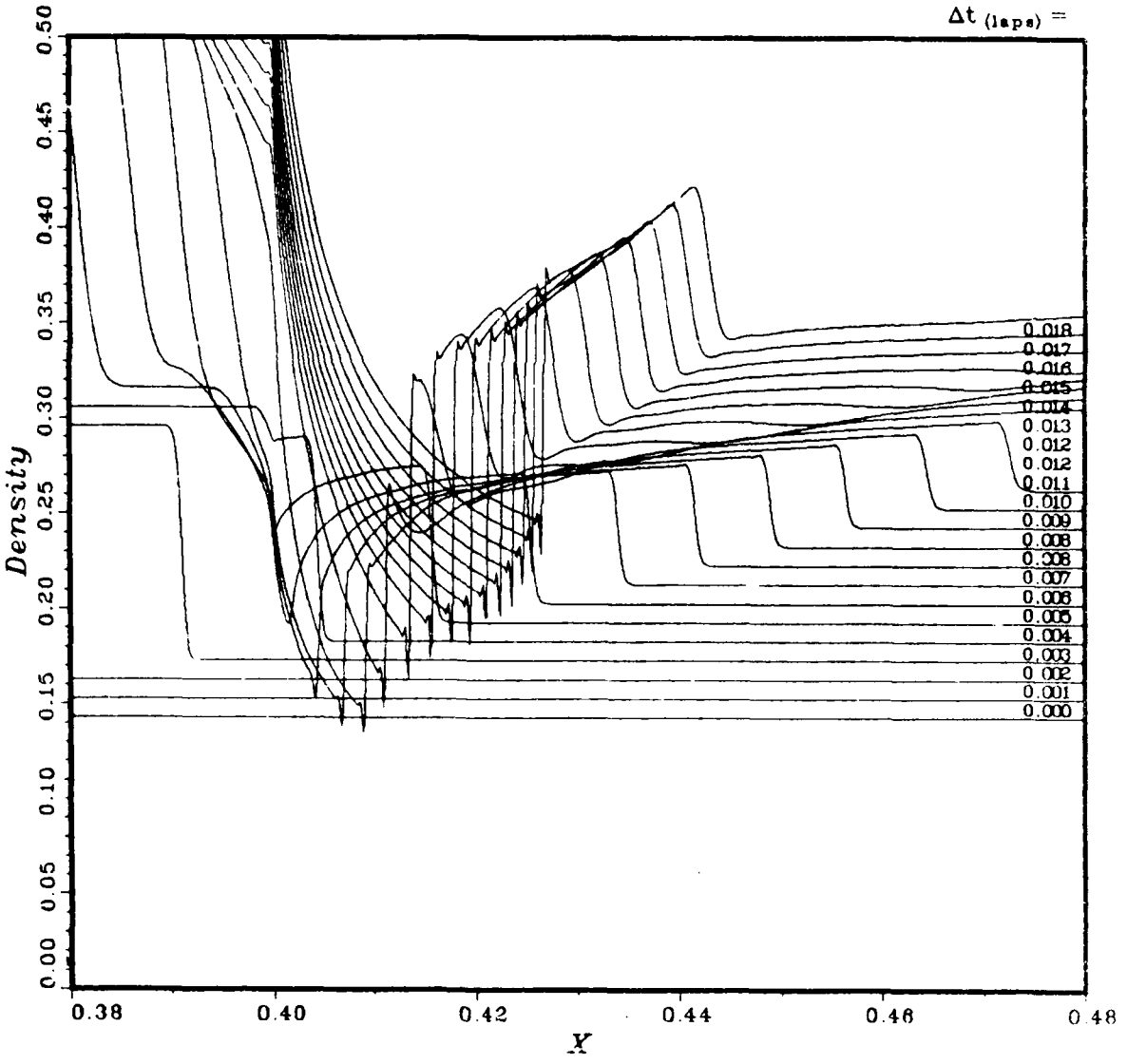


Figure 81. Detail study, density versus distance 0.38 to 0.48

PLOT 3 09.18.49 WED 23 DEC, 1987 JOB-P1029095, ISSCO DISSPLA 10.0

velocity

CASE~ 8h: BRL8 PLOT 1
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

VELOCITY vs. DISTANCE

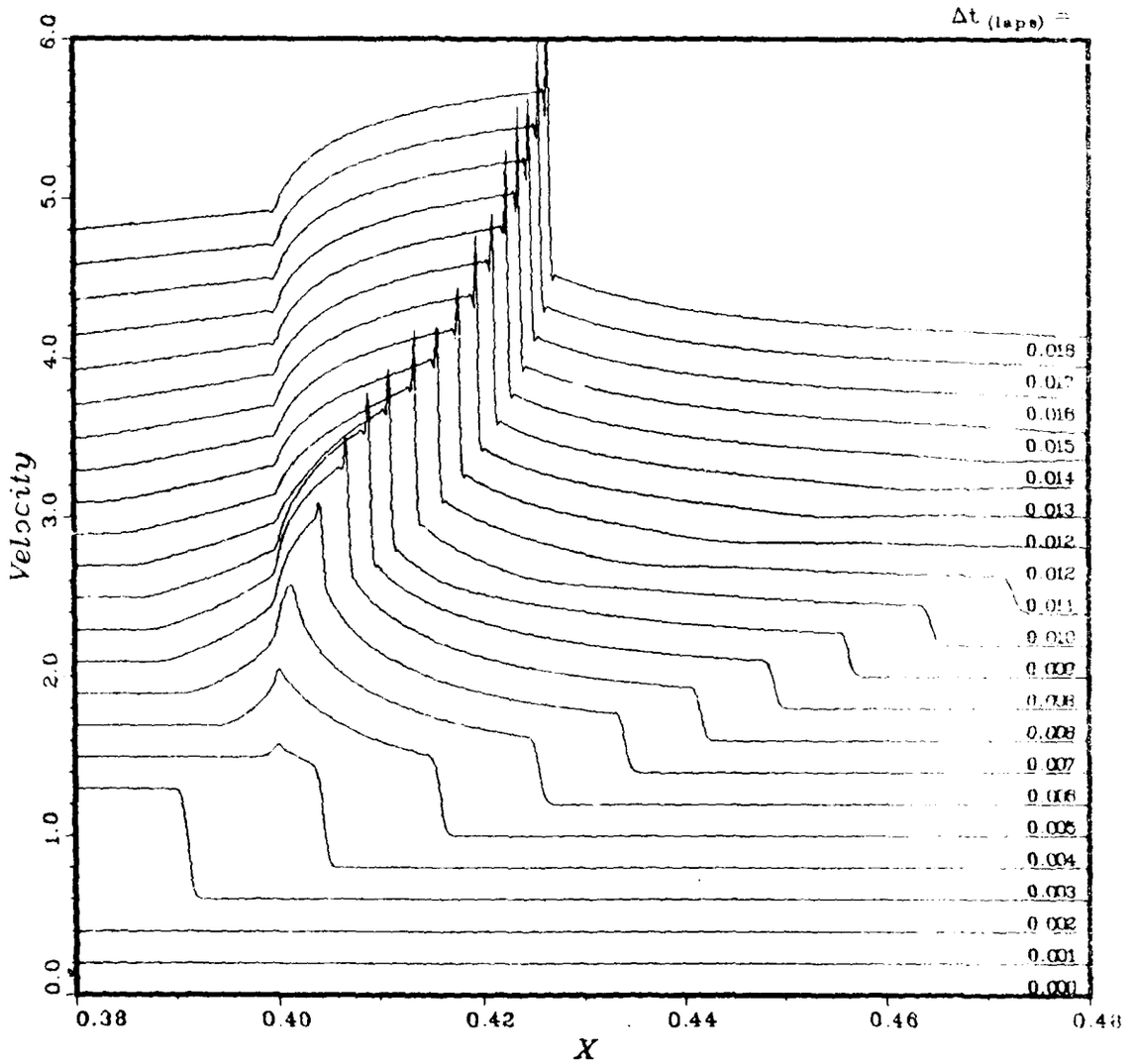


Figure 82. Detail study, velocity versus distance 0.38 to 0.48

sound speed

CASE~ 8h: BRL8 – PLOT
Offset, Δy = 0.0

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

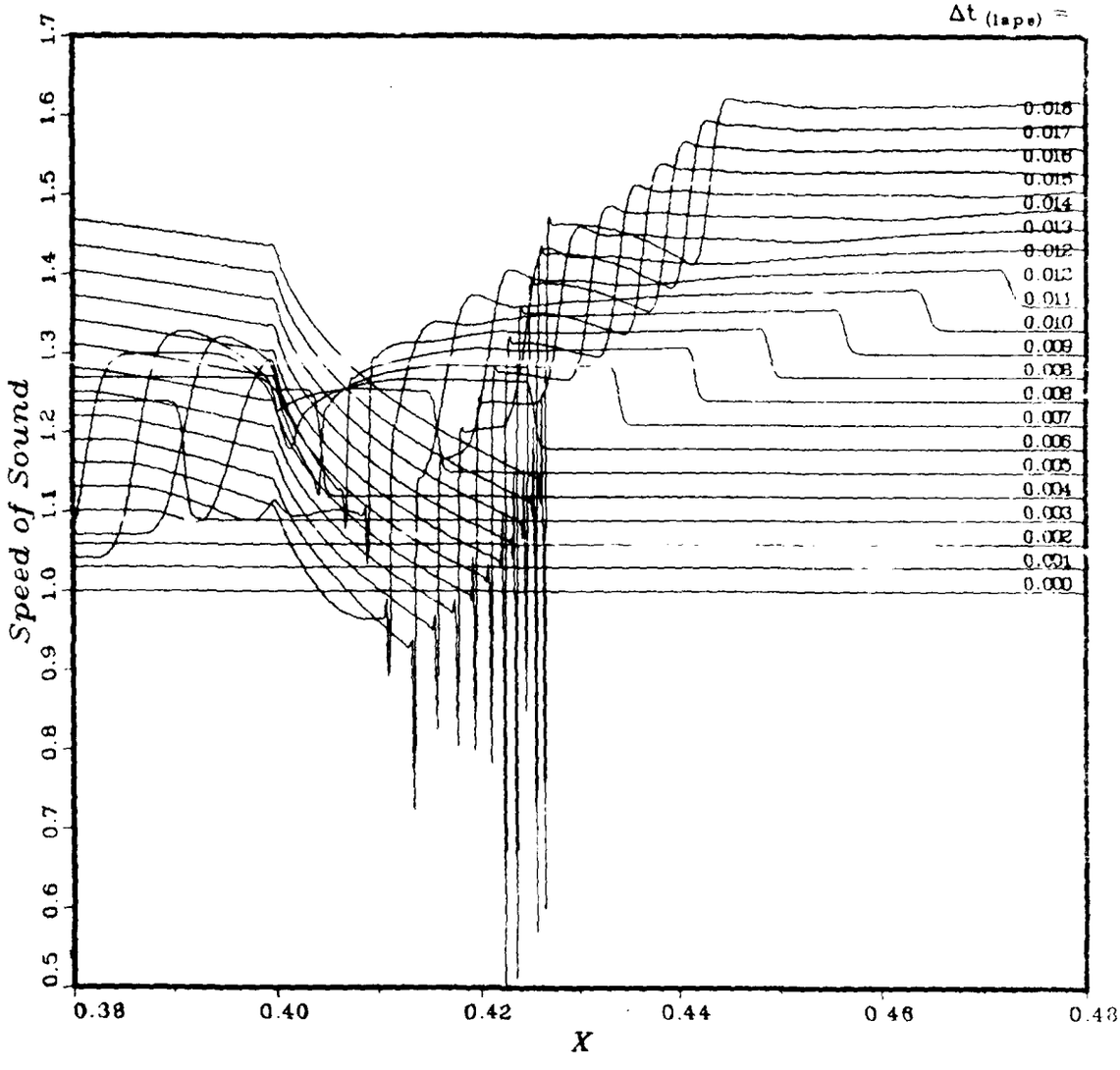


Figure 83. Detail study, sound speed versus distance 0.38 to 0.48

pressure

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.020

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

PRESSURE vs. DISTANCE

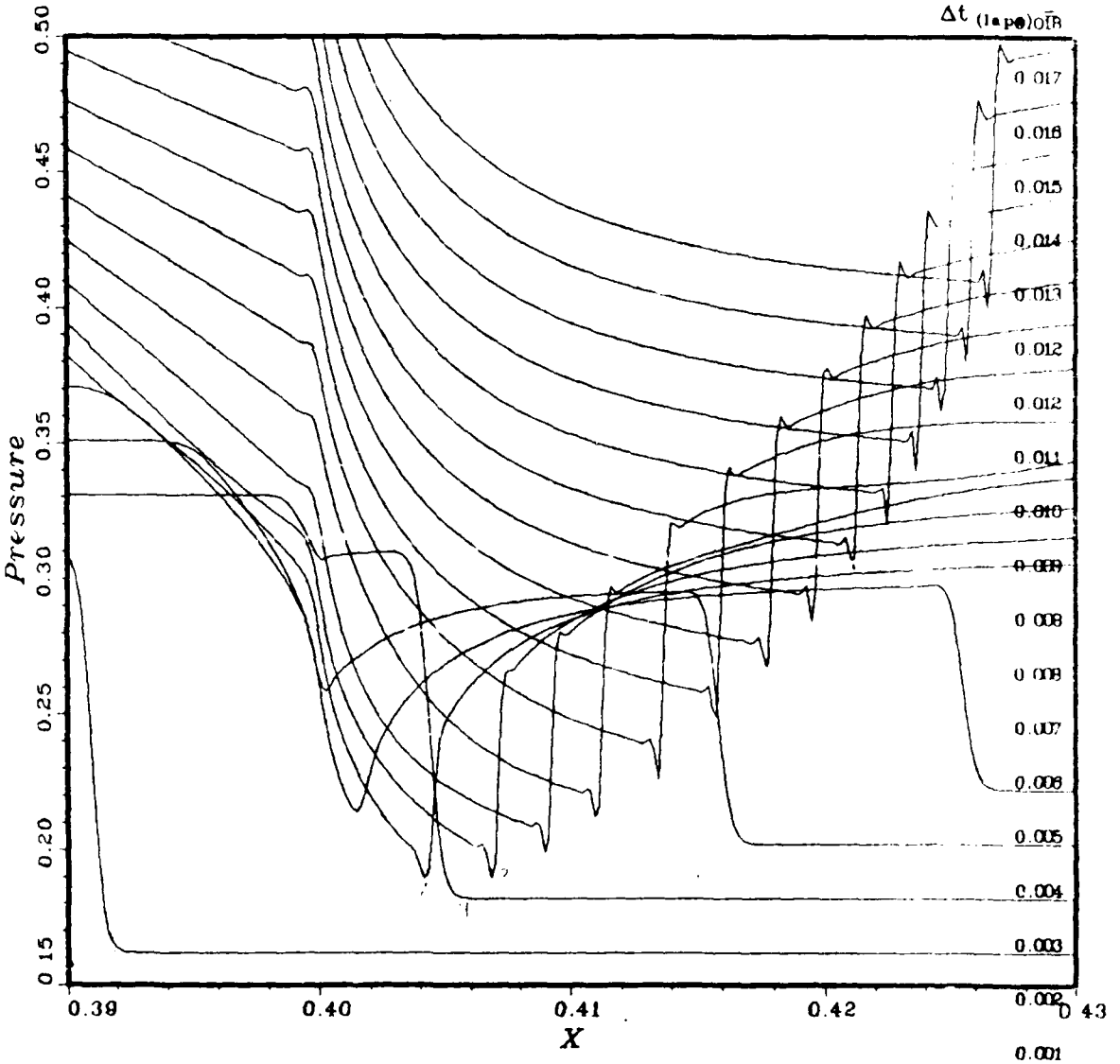


Figure 84. Detail study, pressure versus distance 0.39 to 0.43

density

CASE~ 8h: BRL8 -- PLOT
Offset, Δy = 0.010

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

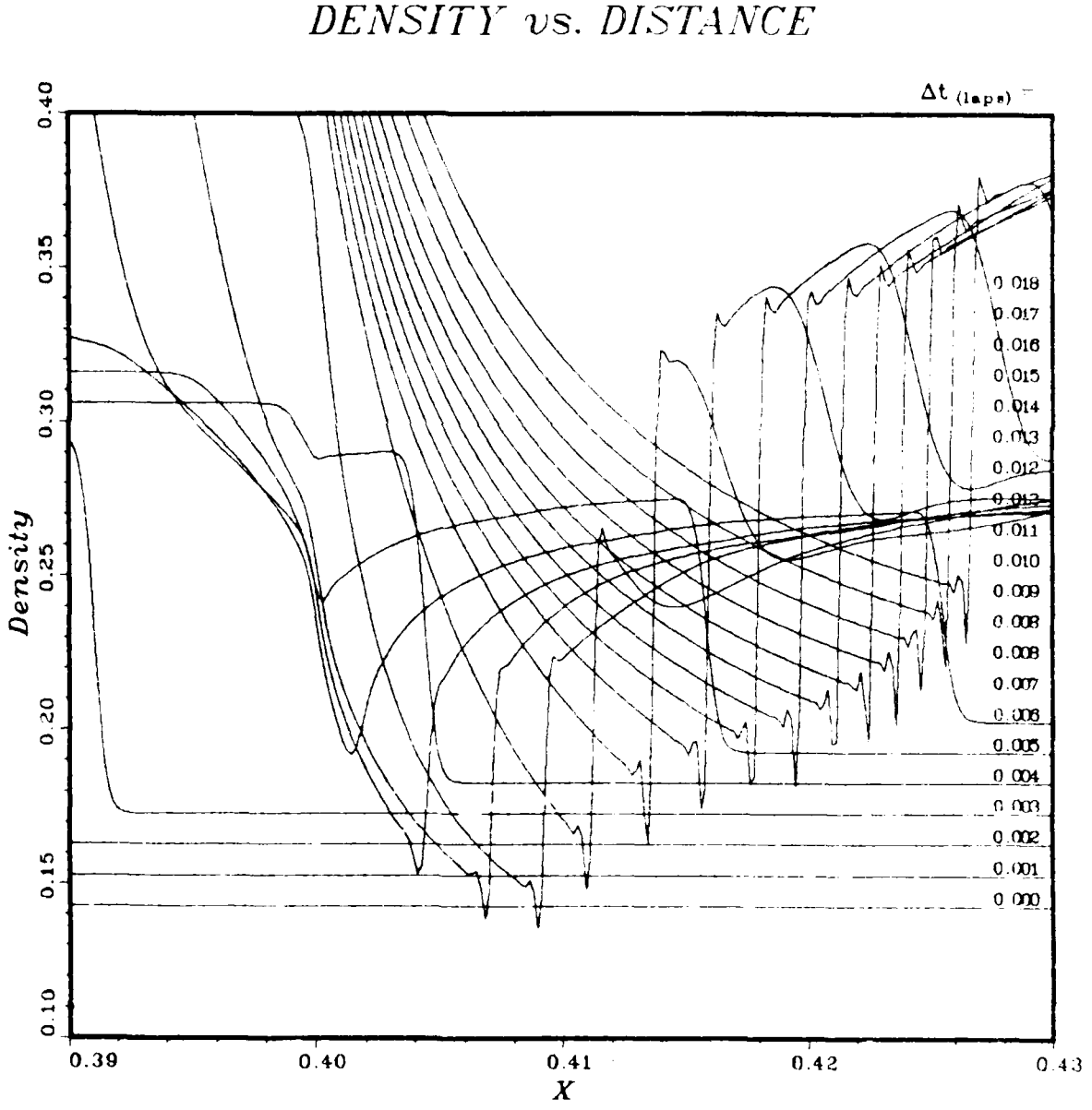


Figure 85. Detail study, density versus distance 0.39 to 0.43

PLOT 3 09.34.17 WED 23 DEC, 1987 JOB-PID30123, ISSCO DISSPLA 10.0

velocity

CASE~ 8h: BRL8 - PLOT 1
Offset, Δy = 0.200

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

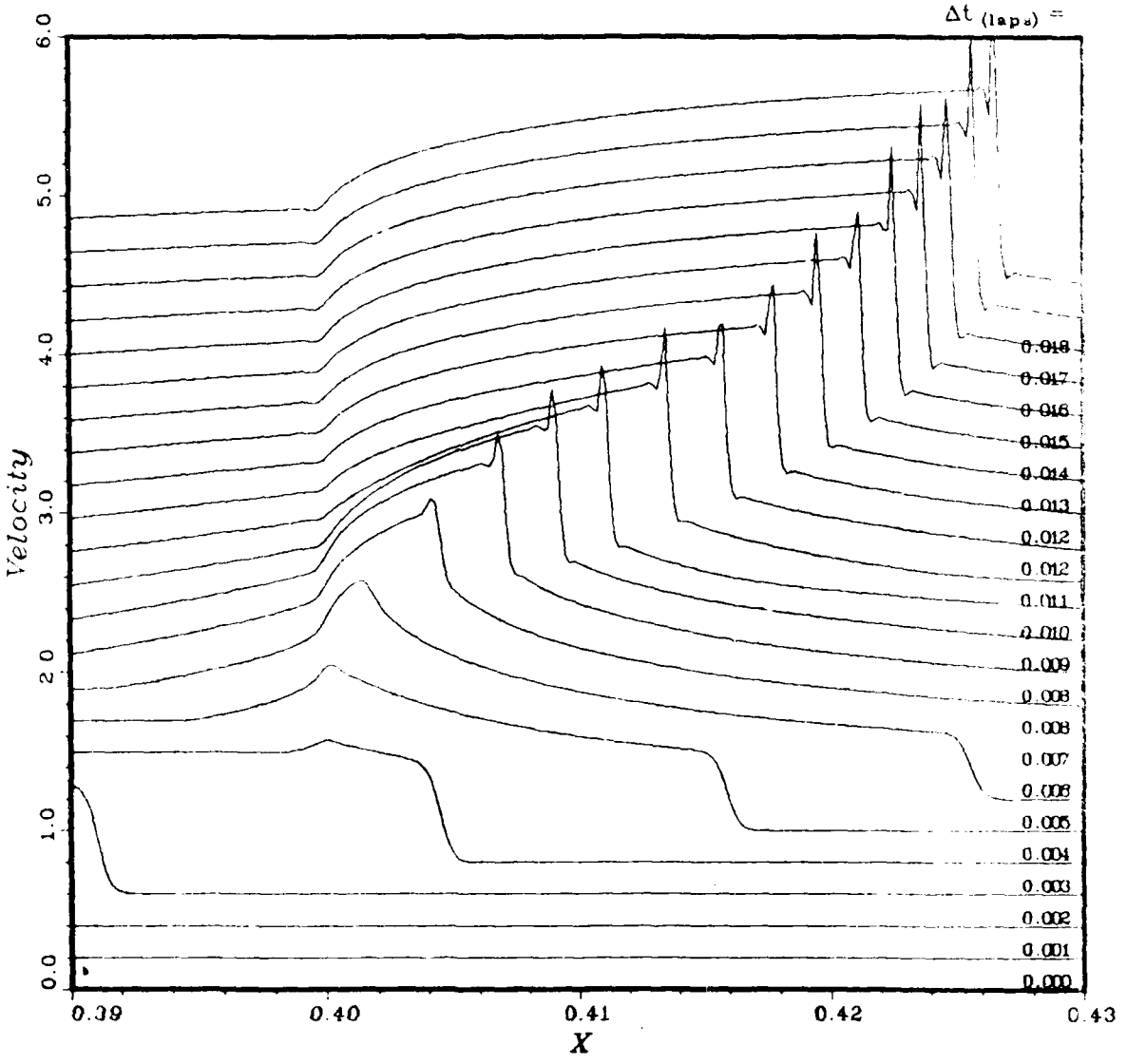


Figure 86. Detail study, velocity versus distance 0.39 to 0.43

sound speed

CASE~ 8h: BRL8 – PLOT
Offset, Δy = 0.0

L_{ref} = 40.00 m
V_{drv} = 276.1 m^3
P_{41} = 7.000; T_{41} = 1.000
$XSTA_i$ = 0.400, 0.450, 0.500, 0.550, 0.600, 0.700

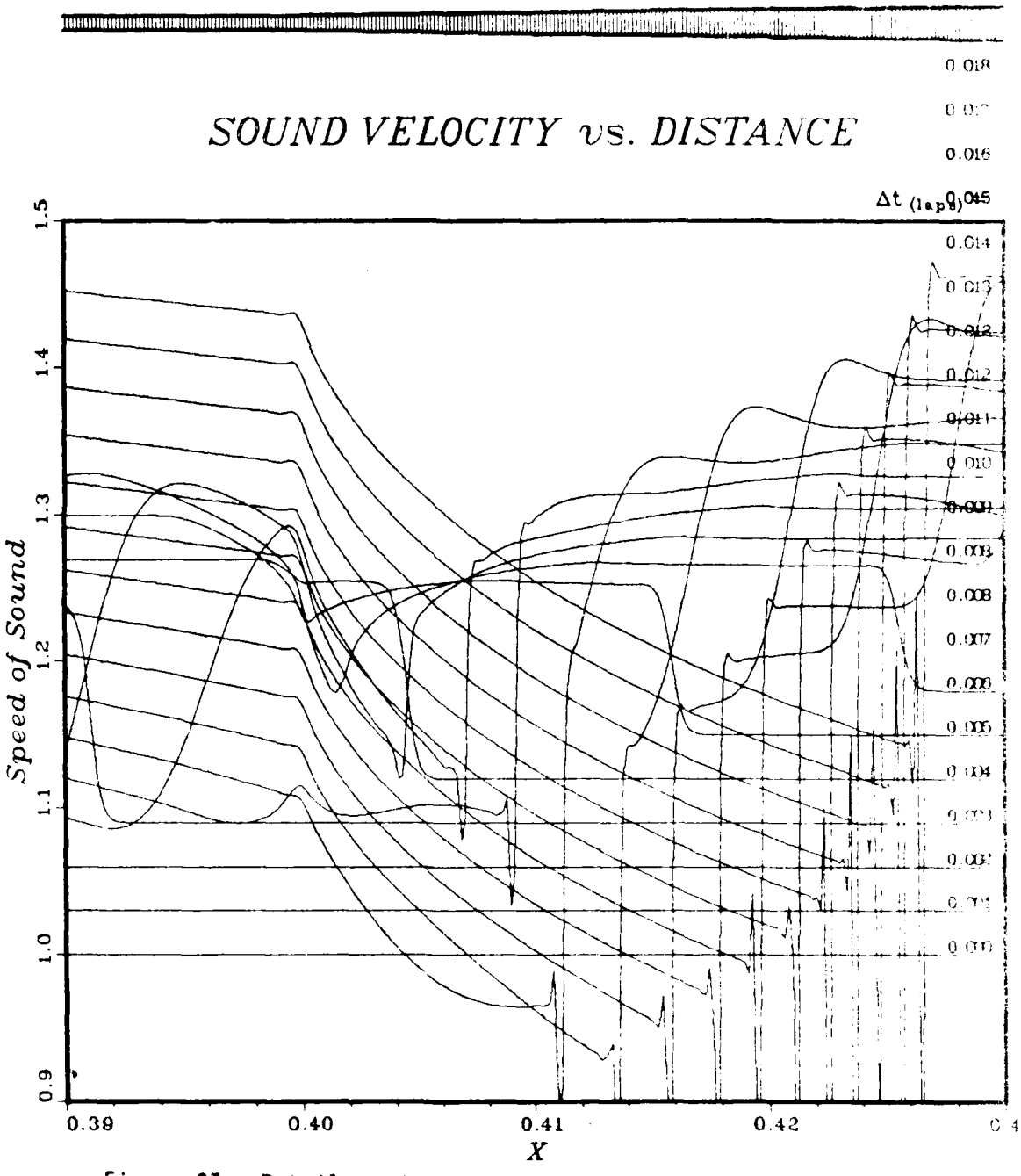


Figure 87. Detail study, sound speed versus distance 0.39 to 0.43

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	= 142.1 kPa	(20.60 ps
L-ref	= 40.00 m	X-sta	= -4.000 m	t-a	= 3.906 ms		
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	= 0.030 s	(0.076 s
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	= 3.174 kPa-s	(0.057 k
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	= 114.0 kPa		
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	= 5.457 kPa-s	(8.724 k

PRESSURE-TIME HISTORY

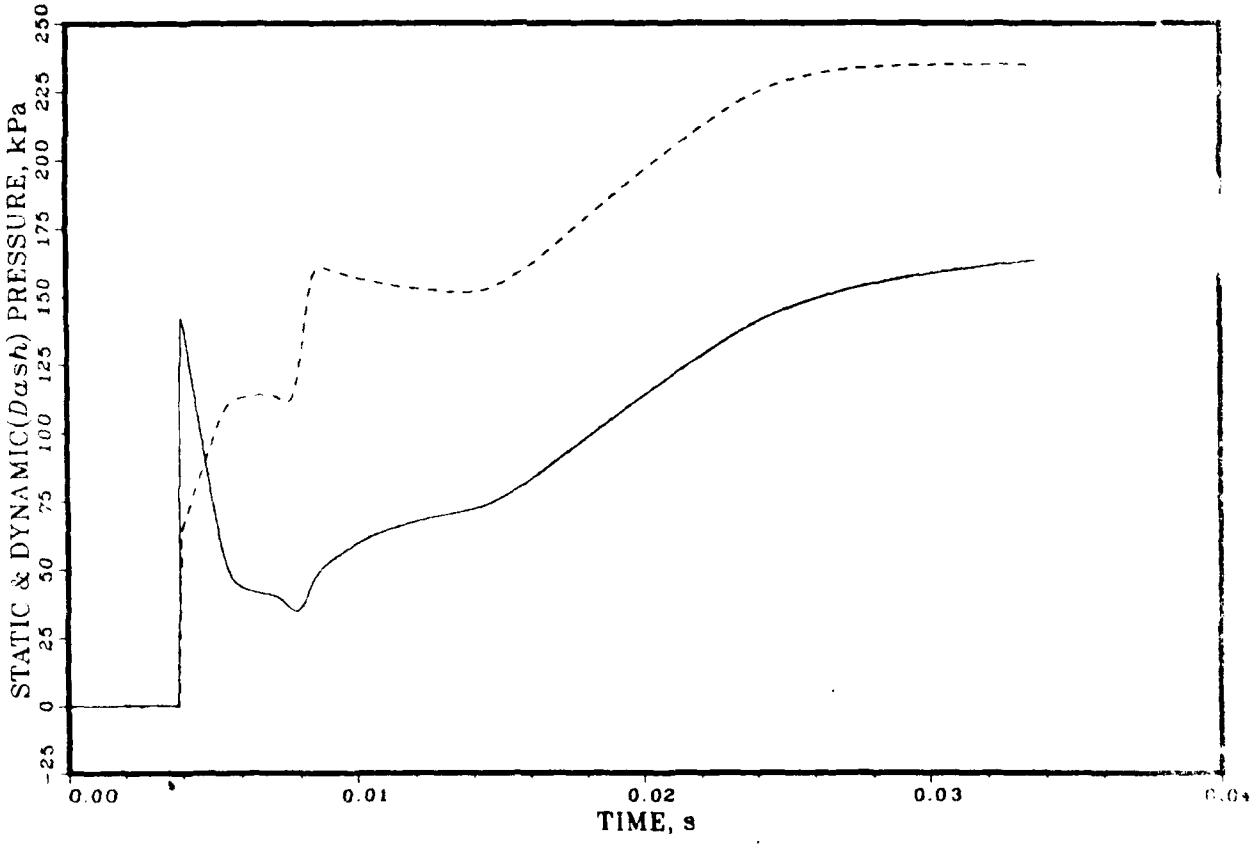
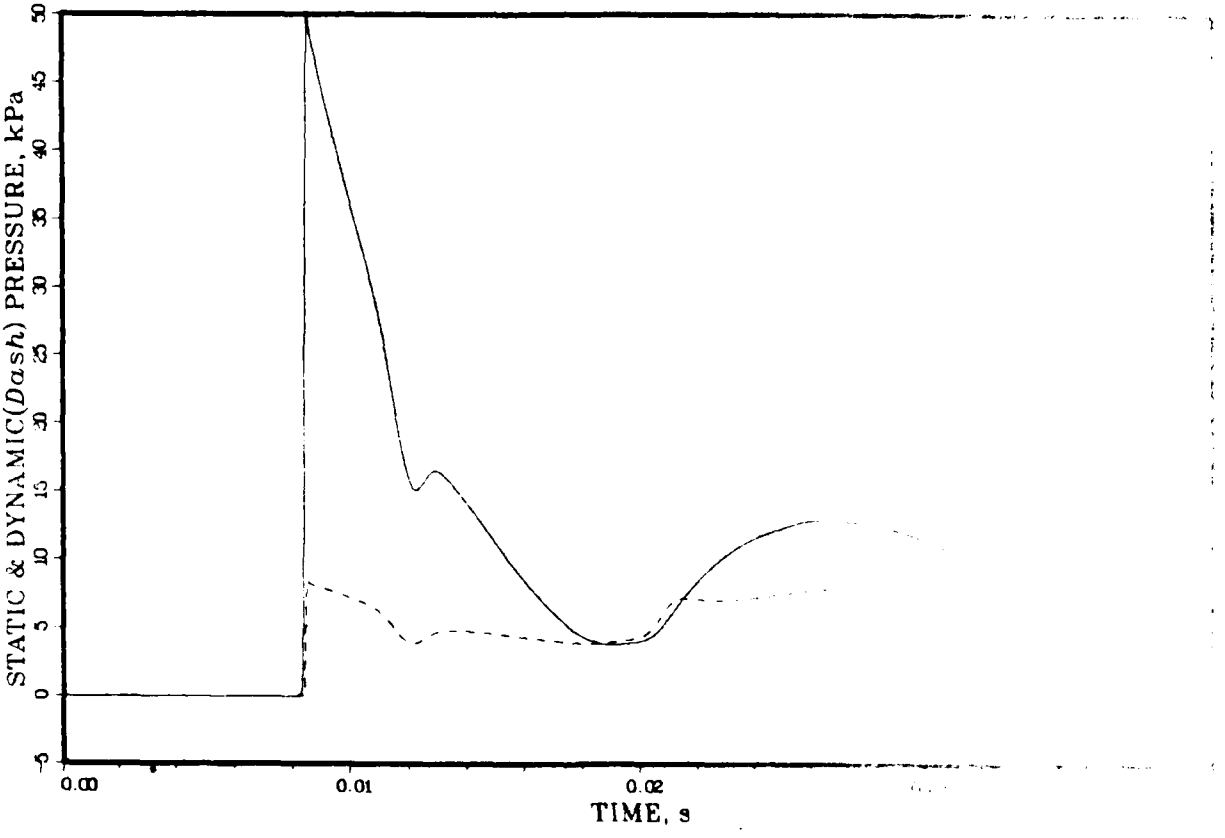


Figure 88. Detail study, pressure versus time at -4 meters

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	[illegible]
L-ref	= 40.00 m	X-sta	= -2.000 m	t-a	[illegible]
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	[illegible]
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	[illegible]
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	[illegible]
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	[illegible]

PRESSURE-TIME HISTORY



PLOT 2 18.34.40 MON 21 DEC, 1987 JOB-P1044795, ISSCO DISSPLA 10.0

Figure 89. Detail study, pressure versus time at -2

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	= 28.39 kPa (4.117 psi)
L-ref	= 40.00 m	X-sta	= 0.000 m	t-a	= 13.58 ms
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	= 0.020 s (0.029 s)
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	= 0.302 kPa-s (0.000 kT)
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	= 2.733 kPa
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	= 0.017 kPa-s (0.000 kT)

PRESSURE-TIME HISTORY

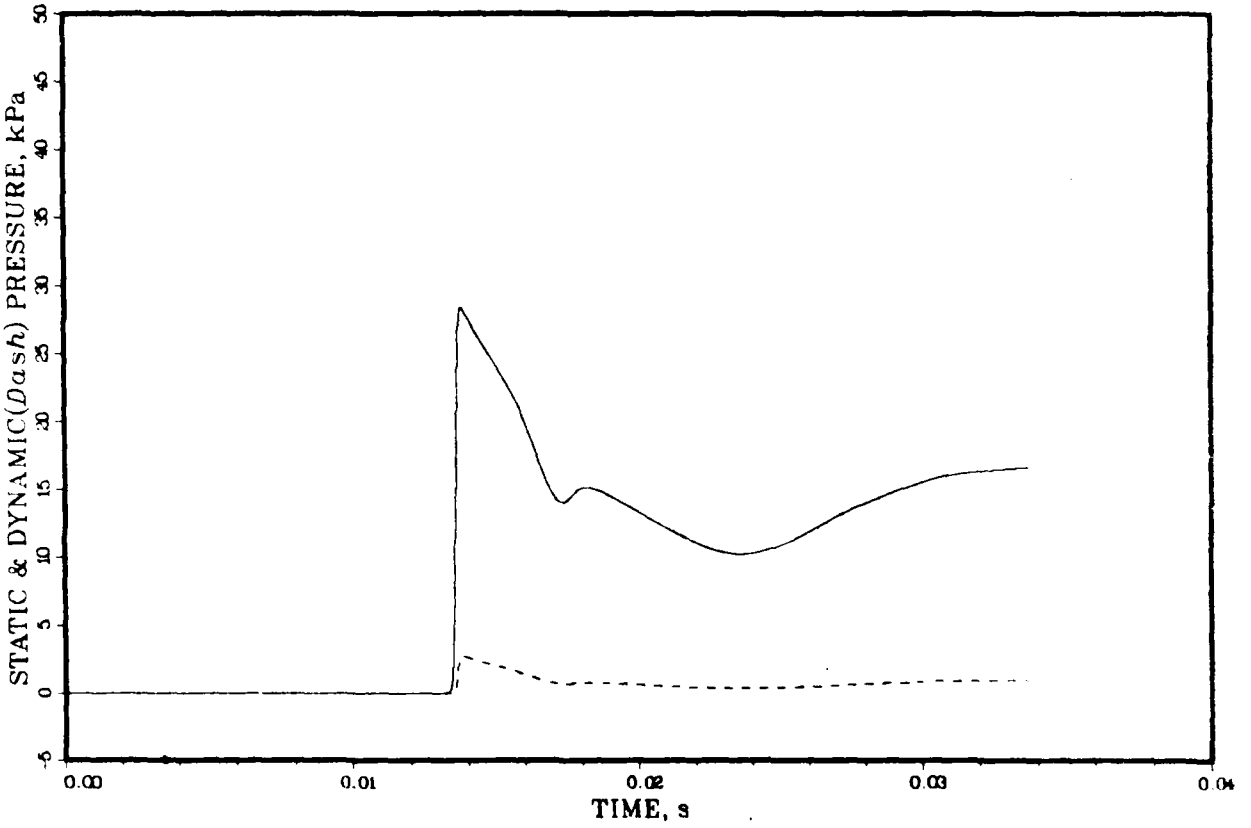


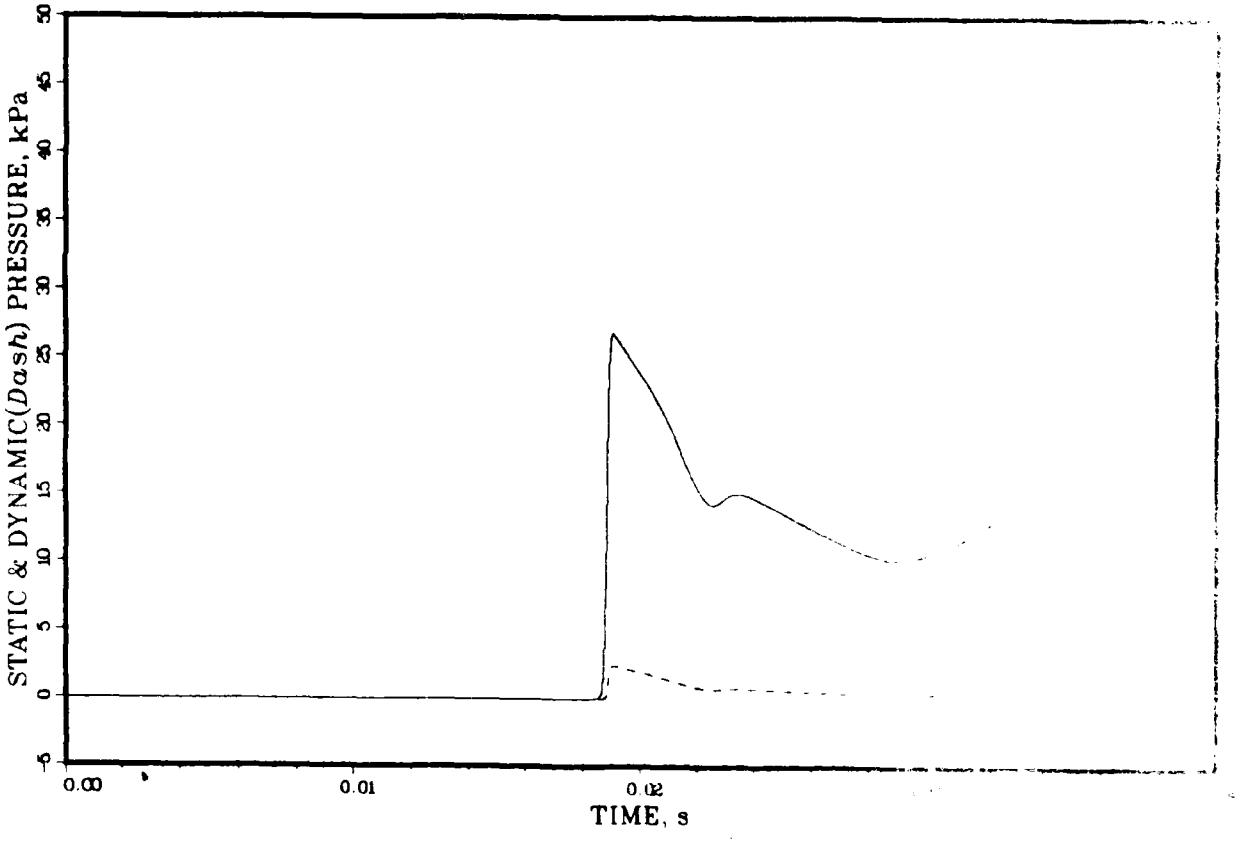
Figure 90. Detail study, pressure versus time at 0 meters

PLOT 3 18.34.42 MON 21 DEC, 1987 Job-r1u44795, ISSCO DISSPLA 10.0

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	= 26.79 kPa
L-ref	= 40.00 m	X-sta	= 2.000 m	t-a	= 18.38 ms
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	= 0.015 s
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	= 0.215 kPa s
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	= 2.483 kPa
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	= 0.902 kPa

PRESSURE–TIME HISTORY



PLOT 4 18.34.44 MON 21 DEC, 1987 JOB-P1D44795, ISSCO DISSPLA 10.0

Figure 91. Detail study, pressure versus time at 2 meters

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	= 25.56 kPa	(3.708 psi)
L-ref	= 40.00 m	X-sta	= 4.000 m	t-a	= 24.17 ms	
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	= 0.009 s	(0.015 s)
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	= 0.150 kPa-s	(0.000 kT)
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	= 2.223 kPa	
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	= 0.009 kPa-s	(0.000 kT)

PRESSURE-TIME HISTORY

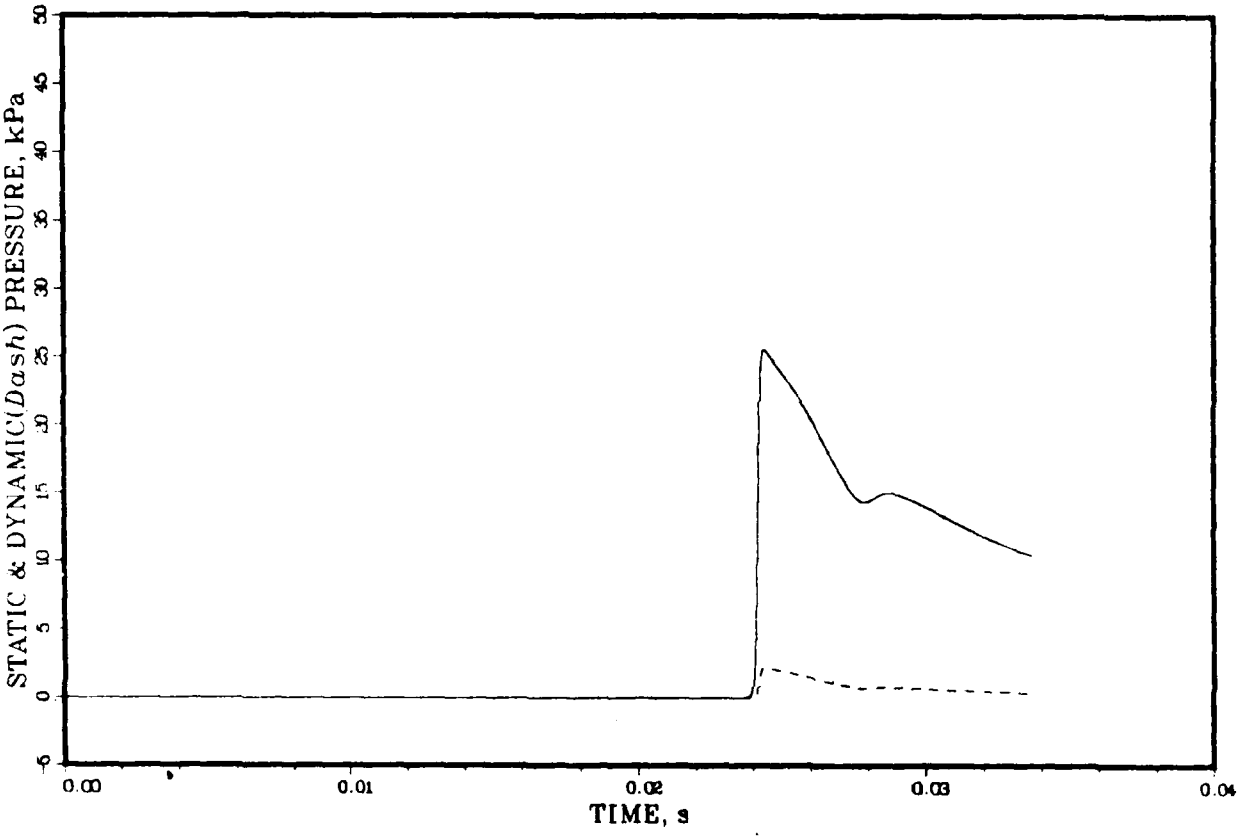


Figure 92. Detail study, pressure versus time at 4 meters

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8h: BRL8			P-so	= 25.56 kPa
L-ref	= 40.00 m	X-sta	= 4.000 m	t-a	= 31.17 ms
L-drv	= 10.00 m	P-drv	= 7.000 atm	PPD	= 0.000
V-drv	= 276.1 m^3	P-amb	= 101.3 kPa	I-so	= 0.150 kPa
L-dvn	= 20.00 m	T-amb	= 288.2 K	Q-s	= 2.323 kPa
L-rwe	= 0.000 m	T4/T1	= 1.000	I-dyn	= 0.000 kPa

PRESSURE-TIME HISTORY

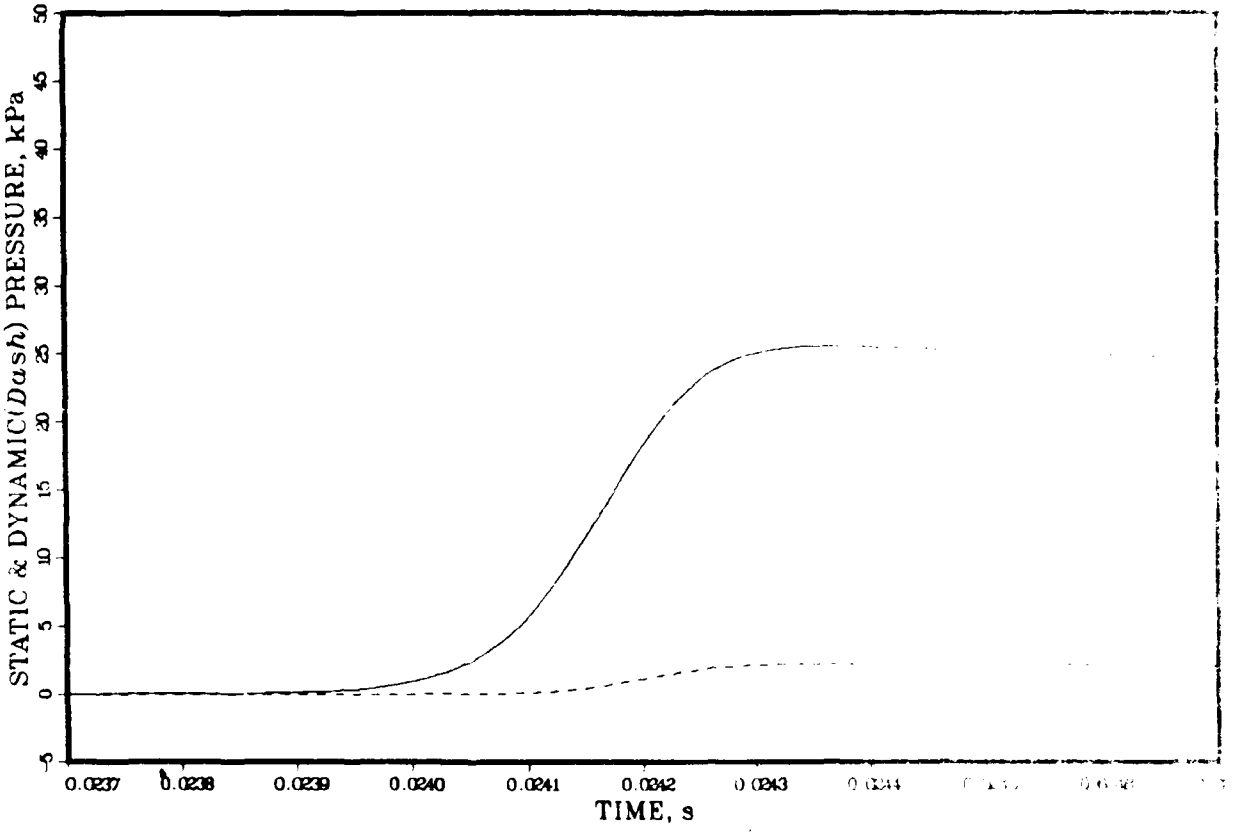


Figure 93. Detail study, pressure versus magnified time

PLOT 5 18.47.03 MON 21 DEC, 1987 JOB=7.044974, 13500 D155PLR 10.0

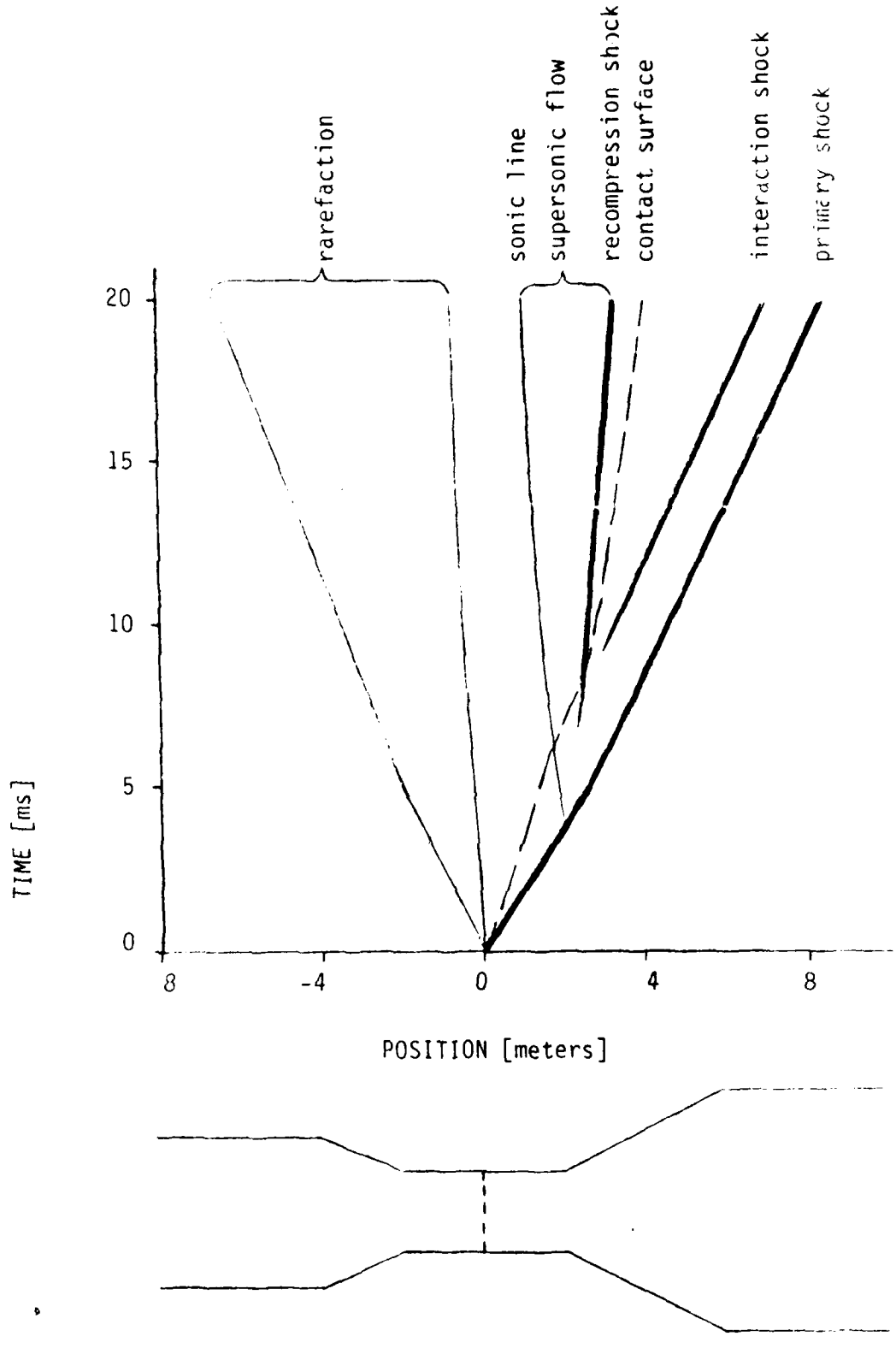


Figure 94. Detail study, characteristics plot

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8s: BRL8			P-so	[illegible]
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	[illegible]
L-drv	= 30.00 m	P-drv	= 7.000 atm	PPD	[illegible]
V-drv	= 508.2 m^3	P-amb	= 101.3 kPa	I-so	[illegible]
L-dyn	= 110.0 m	T-amb	= 288.2 K	Q-s	[illegible]
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	[illegible]

PRESSURE–TIME HISTORY

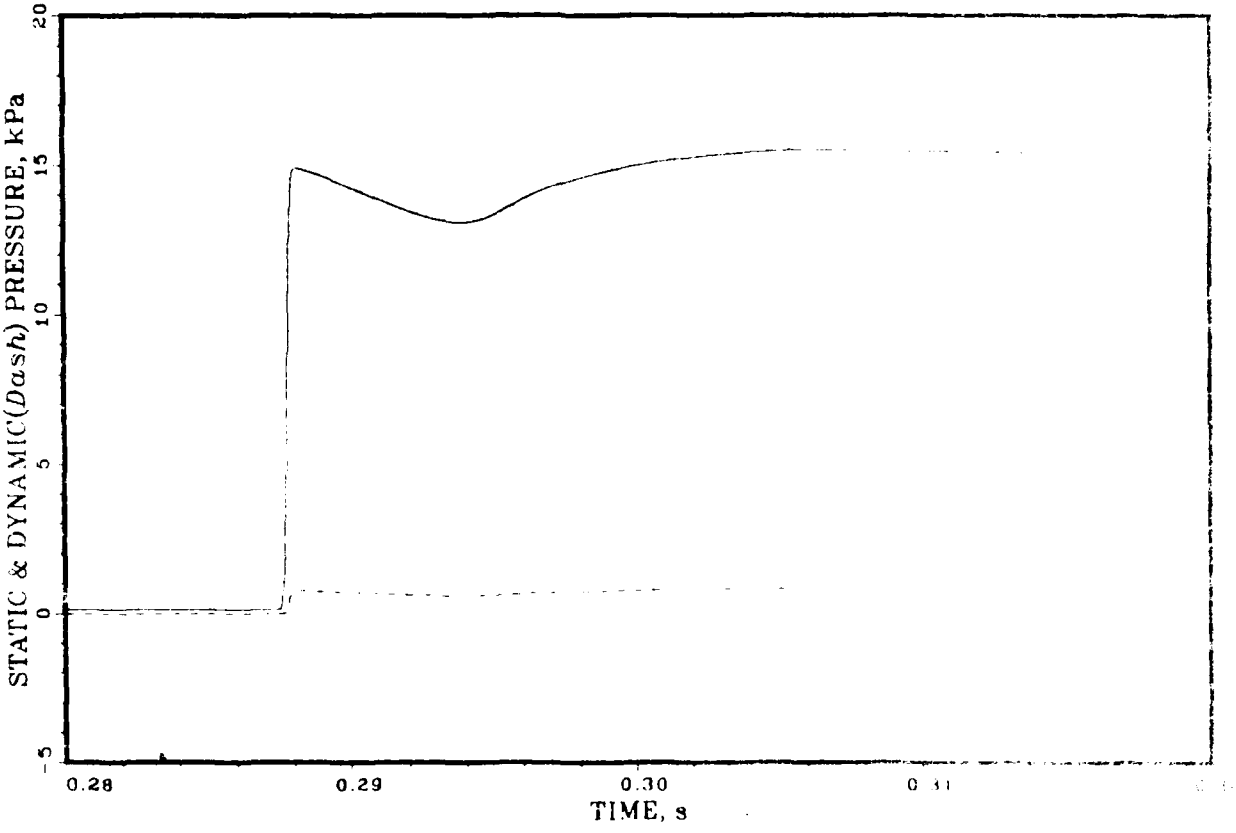


Figure 95. Pressure versus time, case 8, 20ms opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8t: BRL8			P-so	= 12.98	kPa	(1.882 psi)
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 290.6	ms	
L-drv	= 30.00 m	P-drv	= 7.000 atm	PPD	= 0.026	s	(0.026 s)
V-drv	= 508.2 m^3	P-amb	= 101.3 kPa	I-so	= 0.362	kPa-s	(0.004 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.583	kPa	
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.018	kPa-s	(0.014 kT)

PRESSURE-TIME HISTORY

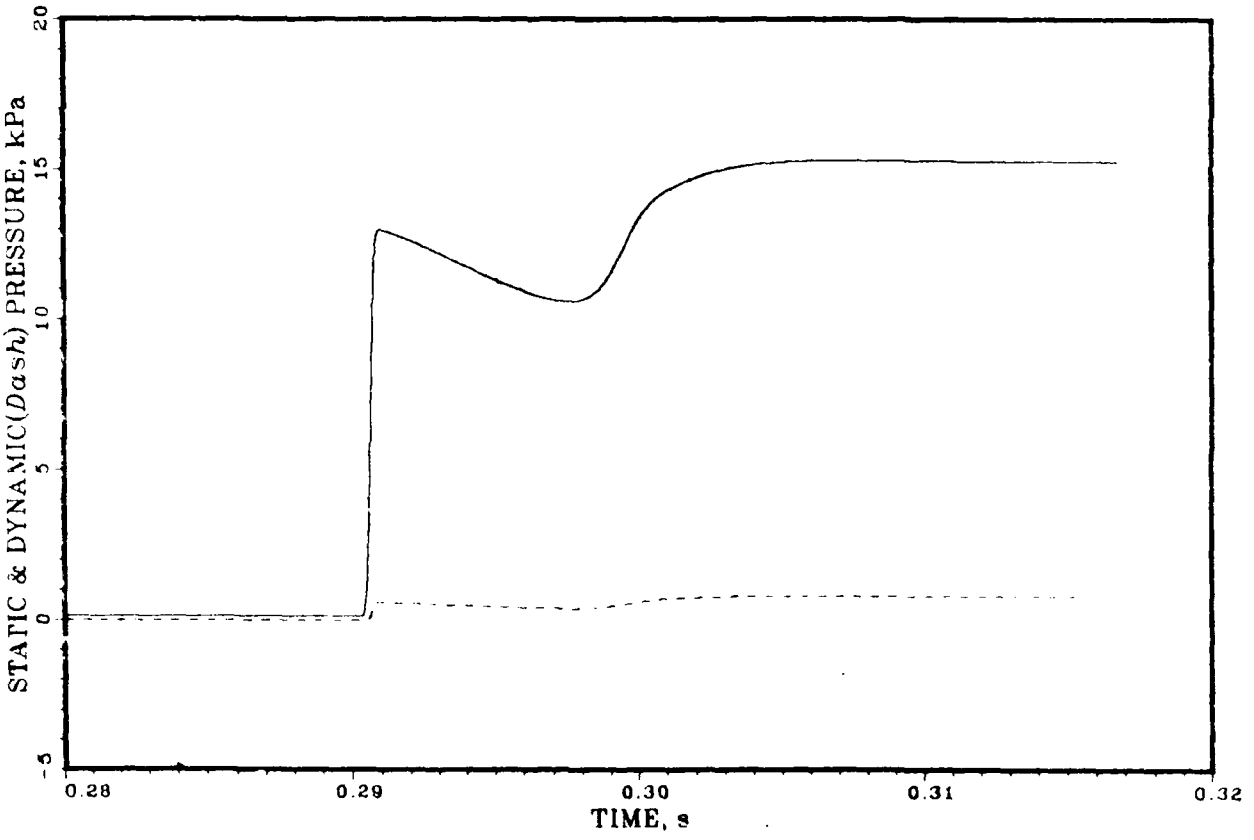
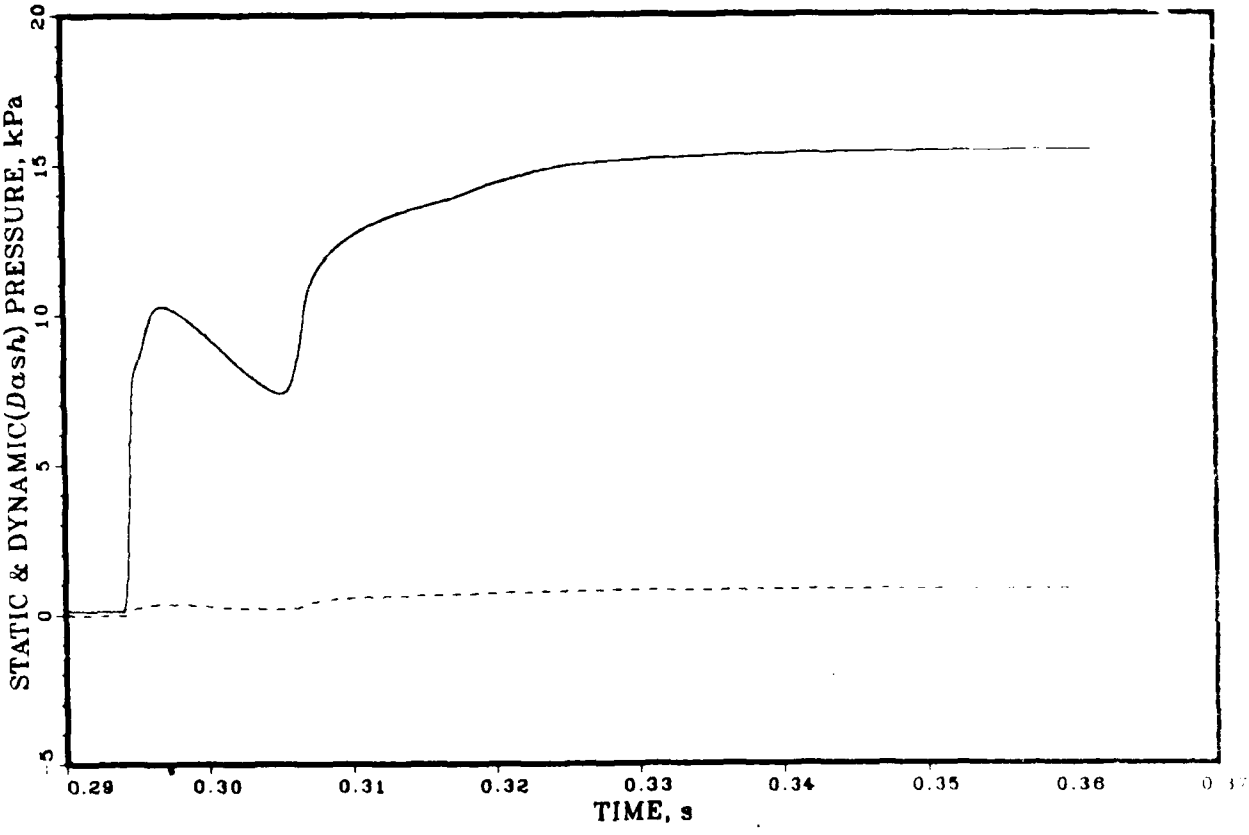


Figure 96. Pressure versus time, case 8, 30ms opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 8r: BRL8			P-so	= 10.31 kPa	(1.495 psi
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 294.6 ms	
L-drv	= 20.00 m	P-drv	= 7.000 atm	PPD	= 0.067 s	(0.212 s
V-drv	= 508.2 m^3	P-amb	= 101.3 kPa	I-so	= 0.915 kPa-s	(0.098 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.369 kPa	
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.045 kPa-s	(0.725 kT)

PRESSURE-TIME HISTORY



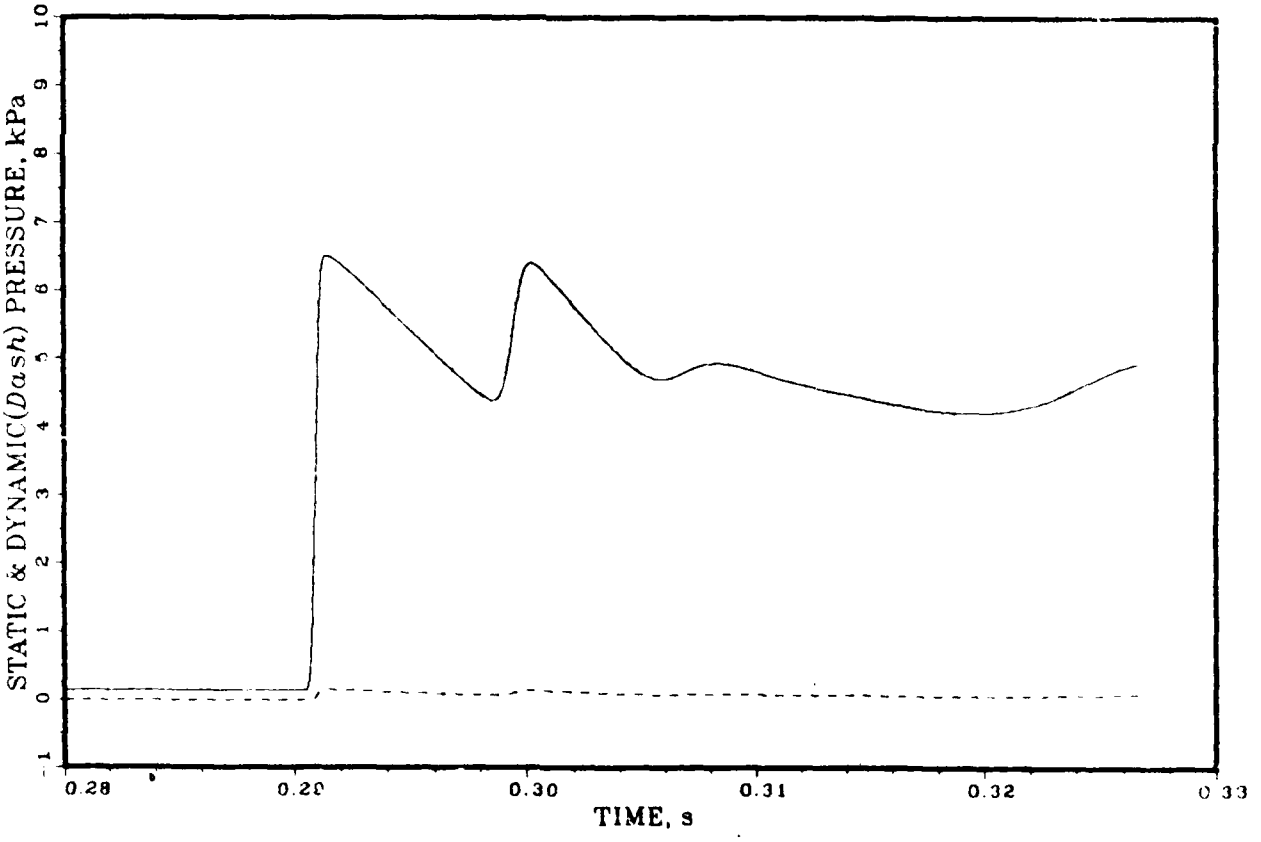
PLOT 1 12.47.18 FRI 8 JAN, 1988 JOB-P1076025, 15500 DISPLAY 10.0

Figure 97. Pressure versus time, case 8, 50ms opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 91: BRL9			P-so	= 6.508 kPa (0.944 psi
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 291.0 ms
L-drv	= 20.00 m	P-drv	= 8.900 atm	PPD	= 0.036 s (0.061 s)
V-drv	= 491.4 m^3	P-amb	= 101.3 kPa	I-so	= 0.175 kPa-s (0.002 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.300 kPa
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.003 kPa-s (0.002 kT)

PRESSURE-TIME HISTORY



PLOT 1 08.33.07 THUR 7 JAN, 1988 JOB=P1016919, ISSCO DISSPLA 10.0

Figure 98. Pressure versus time, case 9, zero opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 9s: BRL9			P-so	= 4.334 kPa
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 299.3 m/s
L-drv	= 20.00 m	P-drv	= 8.900 atm	PPD	= 0.065 s
V-drv	= 490.4 m^3	P-amb	= 101.3 kPa	I-so	= 0.296 kPa
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.300 kPa
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.005 kPa

PRESSURE-TIME HISTORY

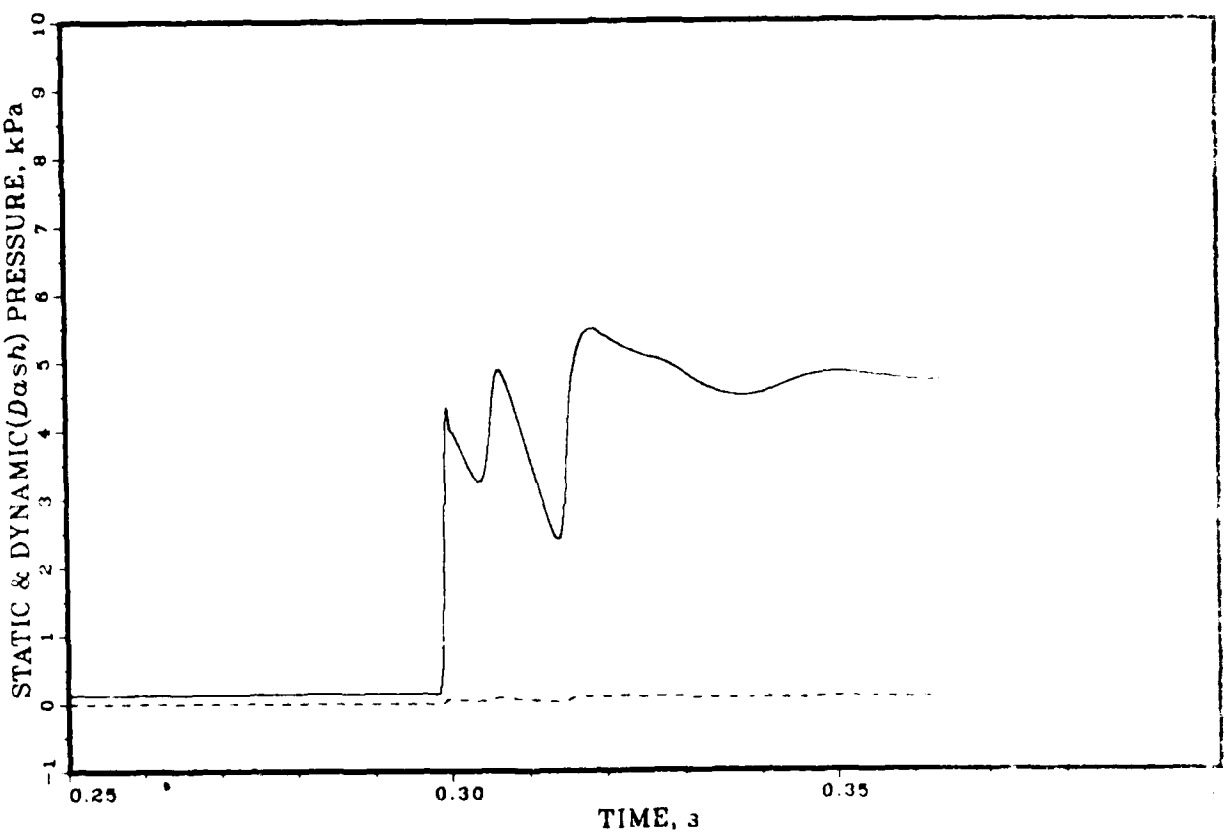


Figure 99. Pressure versus time, case 9, 20ms opening time

SHOCK TUBE WITH CONICAL DRIVER AND NOZZLE

CASE:	= 9r: BRL9			P-so	= 5.022	kPa	(0.728 psi)
L-ref	= 140.0 m	X-sta	= 97.50 m	t-a	= 297.6	ms	
L-drv	= 30.00 m	P-drv	= 8.900 atm	PPD	= 0.029	s	(0.032 s)
V-drv	= 490.4 m^3	P-amb	= 101.3 kPa	I-so	= 0.140	kPa-s	(0.001 kT)
L-dvn	= 110.0 m	T-amb	= 288.2 K	Q-s	= 0.300	kPa	
L-rwe	= 0.000 m	T4/T1	= 1.040	I-dyn	= 0.002	kPa-s	(0.003 kT)

PRESSURE-TIME HISTORY

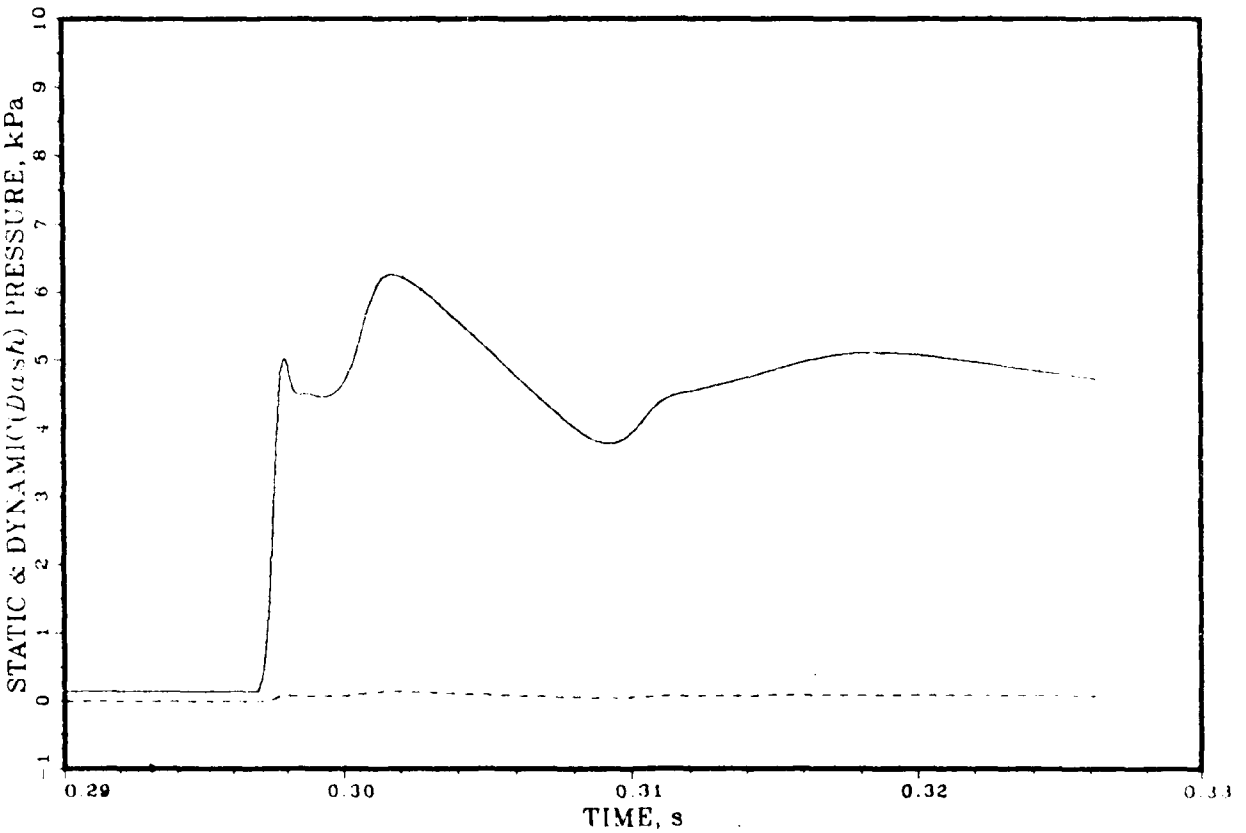


Figure 100. Pressure versus time, case 9, 30ms opening time

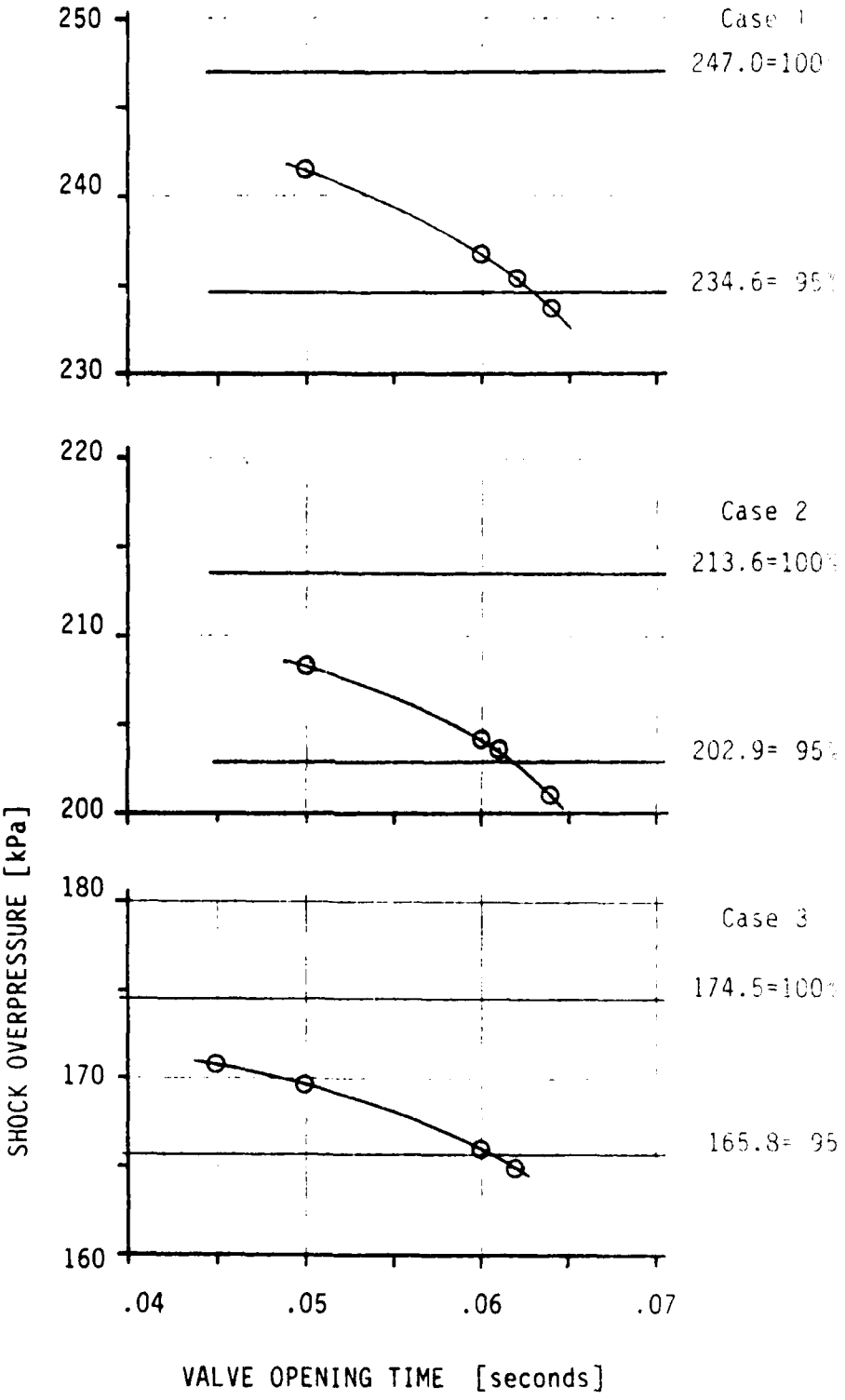


Figure 101. Pressure step versus valve opening time, cases 1, 2, and 3

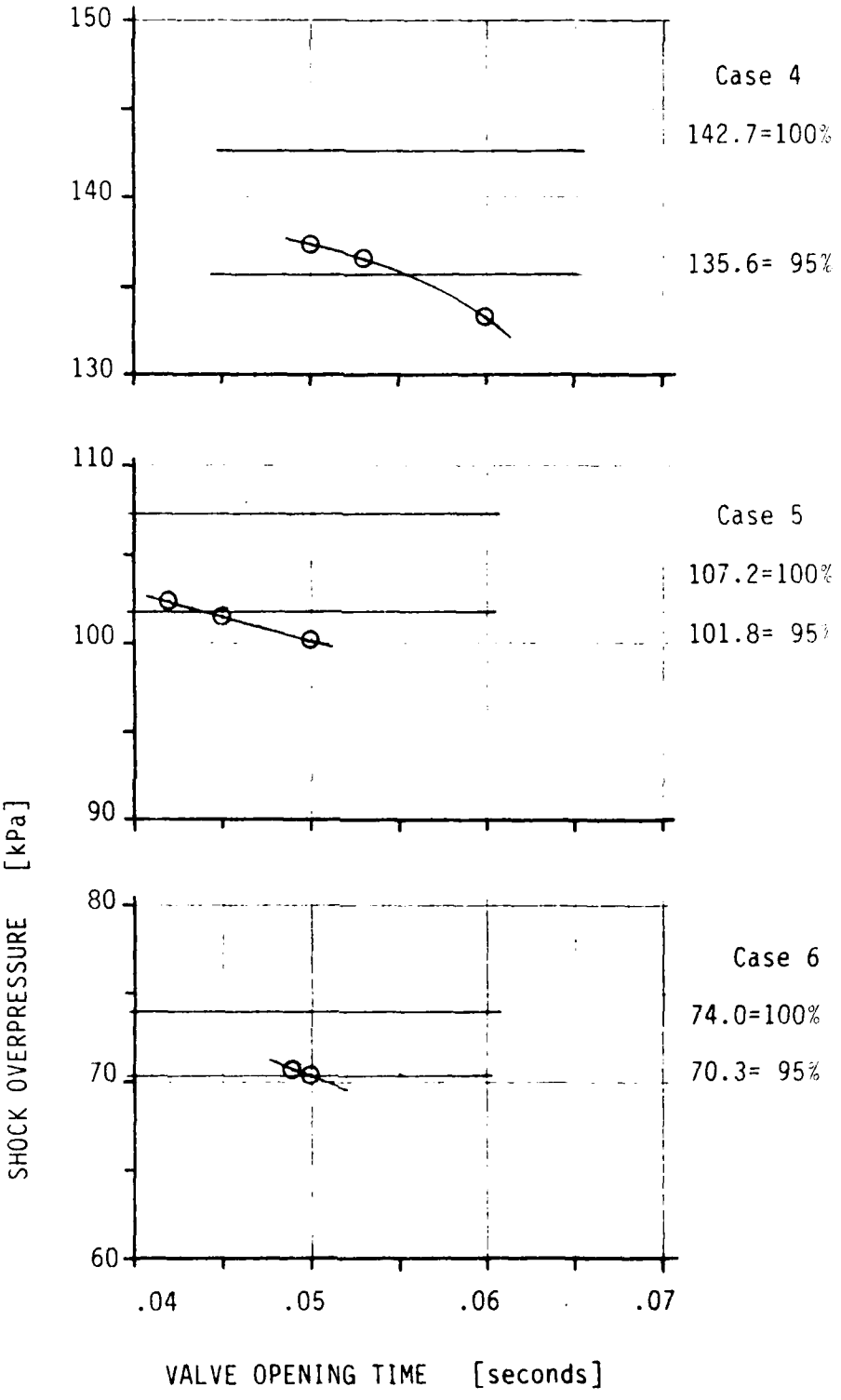


Figure 102. Pressure step versus valve opening time, cases 4, 5, and 6

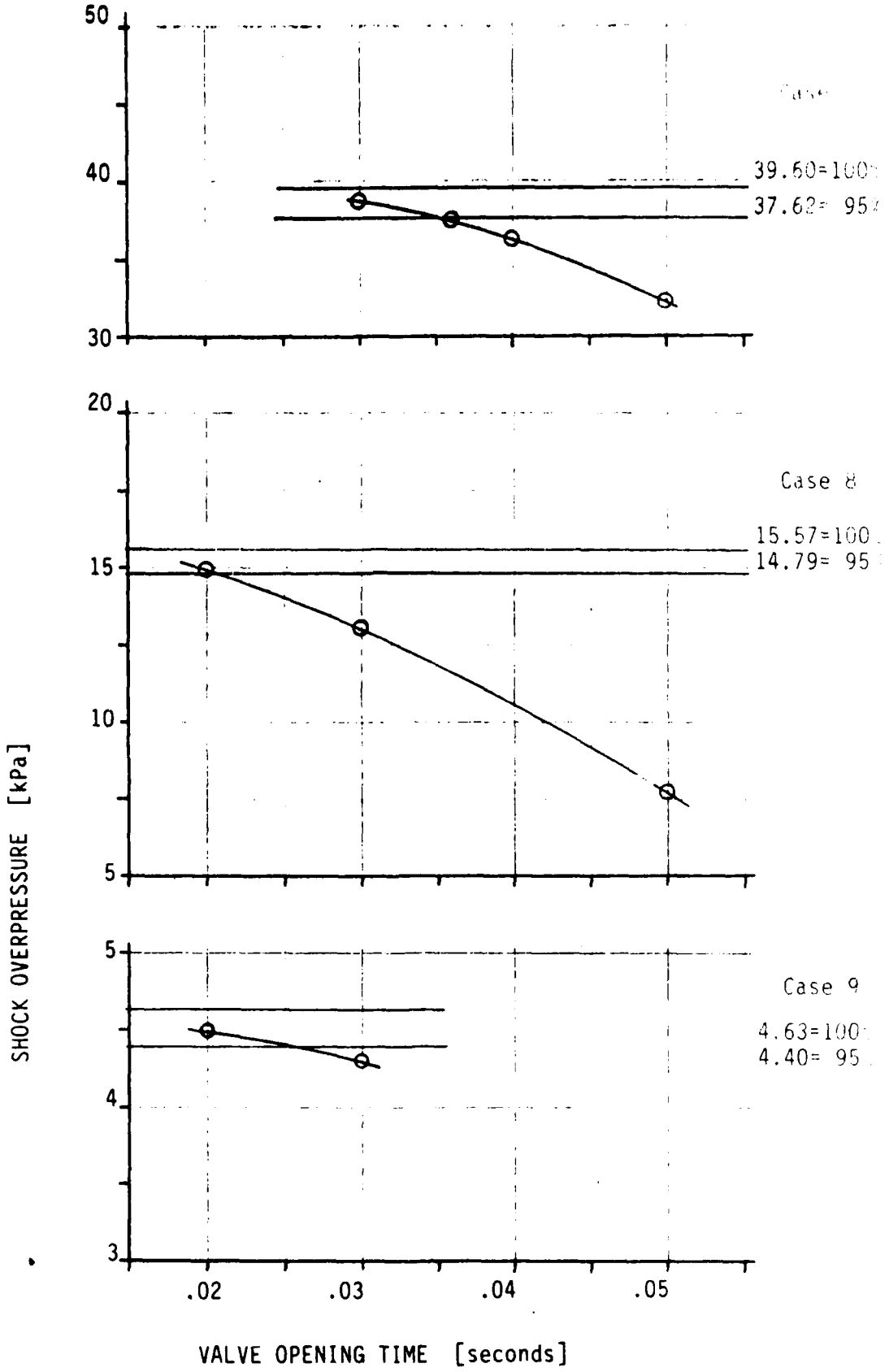


Figure 103. Pressure step versus valve opening time, cases 7, 8, and 9

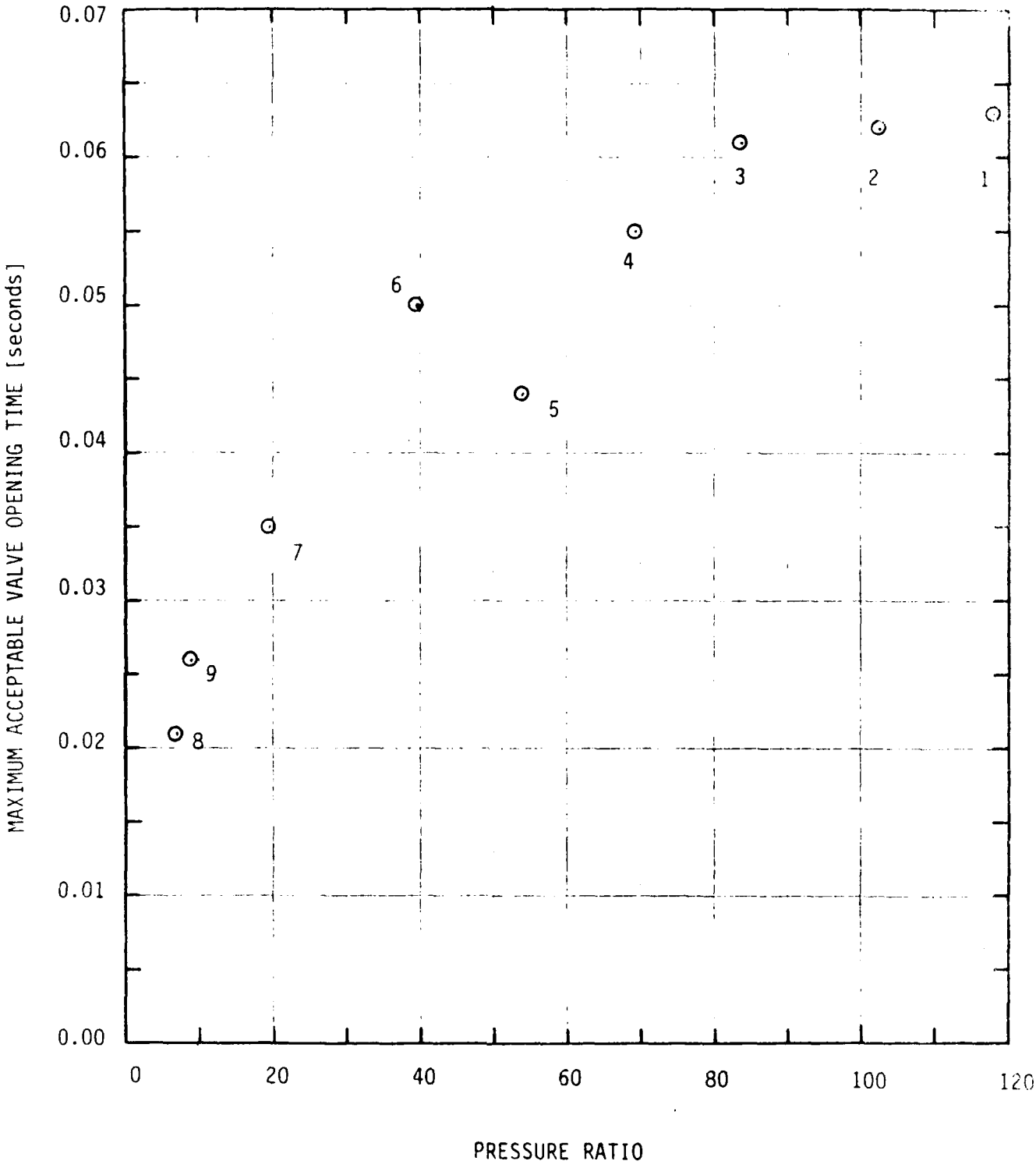


Figure 104. Maximum allowable valve opening time versus driver pressure ratio

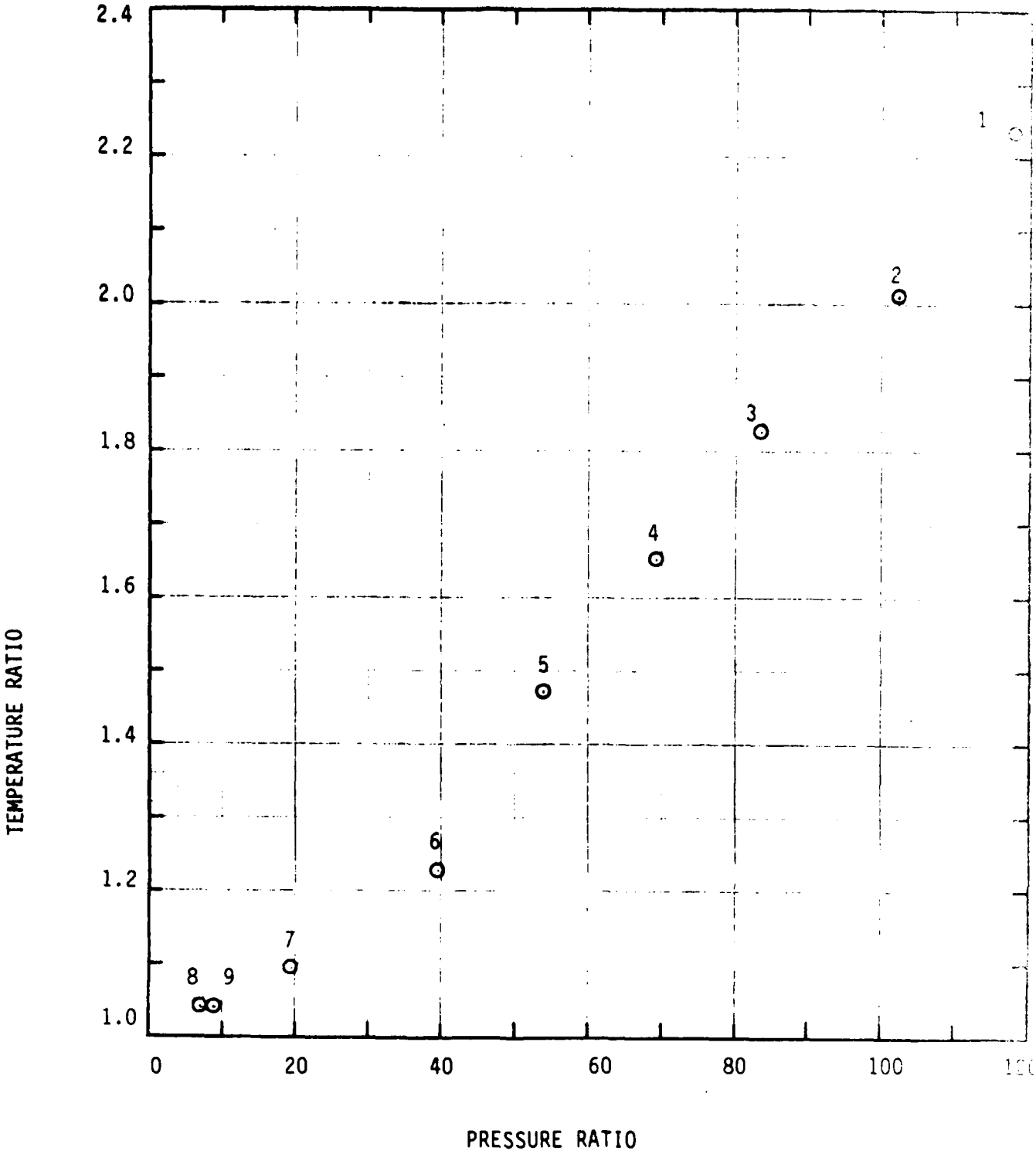


Figure 105. Driver temperature ratio versus driver pressure ratio

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